GEOLOGICAL AND NATURAL HISTORY SURVEY OF MINNESOTA.
N. H. WINCHELL, State Geologist.

May 13, 1893

BULLETIN No. 8.

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Minnesota Coast of Lake Superior.

II.

THE LACCOLITIC SILLS OF THE

North-West Coast of Lake Superior.

BY ANDREW C. LAWSON,
ASSOCIATE PROFESSOR OF GEOLOGY AND MINERALOGY,
IN THE UNIVERSITY OF CALIFORNIA.

WITH A PREFATORY NOTE ON

THE NORIAN OF THE NORTHWEST,

BY N. H. WINCHELL.

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THE NORIAN OF THE NORTHWEST.

PREFATORY NOTE.

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II.

The University of Minnesota
Minneapolis
THE GENERAL LIBRARY

April 15, 1902

Mr. Raymond C. Davis.
Librarian
University of Michigan.

Dear Sir:

In reply to your favor of the 11th inst. regard to the publications of our Geological Survey which you lack I regret to say the Bulletin no 10 is the only one we can supply no. 9 and 4th annual report being out of print. We are sending to your library a copy of the bulletin no. 10.

Yours truly
Wm. W. Folwell.
Libr.

L.M.B.

[illegible] 7th Rept we have and
[illegible] Bull. No 10
Exp.

now lack only Bulletin No. 9 which we have [illegible]
[illegible] Botan. Studies vol. 1.

THE NORIAN OF THE NORTHWEST.

PREFATORY NOTE BY N. H. WINCHELL.

Among the problems which were named in instructions given to Dr. Lawson when he entered upon the season's work for the Minnesota Geological and Natural History Survey along the northern coast of lake Superior, one was the following—*To determine if possible the date and stratigraphic relations of the gabbro invasion.* How well he has answered that question his report on the "Anorthosytes of the Minnesota coast of lake Superior" bears ample testimony. In order, however, that the important bearing which his results have on the geology of the northeastern part of the state, may be made more apparent, it is deemed best to preface this publication with a short exposition of the history of the investigation, and a few paragraphs on the extent of the gabbro rocks and on the significance of the term gabbro.

The reports of the late survey of Wisconsin, particularly those portions contributed by professors Pumpelly and Irving, treat largely of a terrane which they placed at the bottom of the then called "Keweenawan", and which they designated by the general term *gabbro.* This name had already been given by Prof. Streng to the "Rice Point rock" which is seen abundantly at Duluth,* and by Dr. J. H. Kloos in 1871, who had published his preliminary field-studies.† Again in 1877, Dr. Kloos gives further details of the distribution and microscopical character of this rock.‡ He calls attention to "two totally unlike crystalline rocks" at Duluth, one of which is the "gabbro or hypersthene rock", which he says had since the examination by Prof. Streng, actually proven to be gabbro, and which has an "enormous preponderance of labrador plagioclase", and great paucity of other elements which are "with difficulty detected between the feldspar crystals, and can only be distinguished with sufficient clearness in thin sections". The

* Neues Jahrbuch, 1877. See a translation in the Eleventh Minnesota report 1882.
† Zeitschrift der Deutschen Geologischen Gesellschaft, p. 417; translation in the Tenth Minnesota report. Compare page 194, where the Duluth rock is said to have "a resemblance to gabbro, or hypersthenyte".
‡ Zeitschrift der Gesellschaft für Erdkunde zu Berlin. Bd. XII, 1877. Translation in the Nineteenth annual report. Minnesota survey, pp. 81–121.

other crystalline rock described by Kloos at Duluth is the "porphyry-like melaphyr", which appears near the lake shore. He calls attention to the contrast which it presents to the gabbro, and to its similarity with the rock at St. Croix Falls. This rock is not only porphyritic but also amygdaloidal. The exact field relations between these two he could not make out, although it has since been ascertained that the melaphyr lies above the gabbro.

The Wisconsin geologists have described what plainly is the same formation. It occurs in the "Bad river region", and its areal distribution is represented on sheet XXII, (accompanying Vol. III, of that report). Of the three classes into which the rocks of the Keweenawan system are divided by Prof. Pumpelly, the third is "Granular, plagioclase diallage rocks", and in this class he places solely "gabbro",* but recognizing some variations. Prof. Pumpelly considers that phase which Streng named "hornblende gabbro", as one of the variations of his series. In addition to the soda-lime feldspar, labradorite, he also frequently mentions the lime feldspar, anorthite, as an essential and predominant ingredient. He allows the name diabase sometimes to apply to a rock containing anorthite, but when diallage appears with the usual associates, such as a plagioclase-feldspar, titaniferous magnetite and perhaps biotite and augite, the rock is put in his third class under "gabbro". In thus adhering to the presence or absence of diallage in the rock as the principal criterion for its name in his series, he followed the principle and the practice of most of those lithologists who had then studied these rocks.

Later in the same volume are several other reports on these rocks. Prof. Irving's appears on pp. 168–83. He places the Bad river gabbro belt at the base of the Keweenawan series, and makes the important statement that this rock "appears to alternate with the ordinary diabase". If there be no mistake in this observation it will be found to go a long way toward establishing the idea that the gabbro belt is linked inseparably with the diabases of the Keweenawan. It does not appear, however, that the details of this alternation have been given by Irving, nor by any other observer. It may be that Irving refers here not so much to a structural interbedding as to a geographical succession of belts or areas. From such a succession, *i. e.* one of geographical alternation, an observer with Prof. Irving's preconceived notion of the relation of the gabbro to the Keweena-

* Lithology of the Keweenawan system. Wisconsin Report, Vol. III, p. 29, 1880.

wan, and the intergradation of its rocks petrographically with those of the Keweenawan, would almost inevitably infer a structural interbedding. Yet it is quite probable that the alternation was a geographical one, and hence indicates an unconformable overlying of Keweenawan surface flows on a series of ridges of gabbro, followed by abrasion and plowing such as that produced by the Glacial epoch.* In this gabbro belt, according to Prof. Irving's descriptions there are two varieties of gabbro, viz: 1st.—That which lies farthest south, a bluish-gray to nearly black, highly crystalline rock, varying in texture from very fine to very coarse-grained when the individual crystals reach two or three inches in length. The normal constituents are commonly labradorite, "augite or diallage", magnetite or titanic iron, and olivine, the last not being invariably present. Biotite is also common. 2nd.—In the more northern portions of the principal gabbro belt are found subordinate belts of a rock which is red-and-black-mottled, or red-black-and-gray-mottled, coarse-grained though never so coarse as the other variety, and marked by a greater amount of titanic iron. The ingredients of this rock are the same as those of the other variety, except that olivine is only rarely present, and is then apt to be changed to a greenish mineral, and the plagioclase is sometimes brick red. "The augitic ingredient in this rock is always highly foliated,"† and in some cases it is uralitized and even converted to a greenish chloritic substance. After a somewhat generalized microscopical description of each variety Prof. Irving concludes that his observations bear out the conclusions of certain European lithologists as to the subordinate importance of the foliated condition of augite, "by which gabbro is ordinarily separated from diabase, of which it would seem to be merely a phase". Yet Irving retained the name, both in his descriptive text and in his maps, "not only because most of our rock is very close to the typical European gabbros, but more especially because it is so sharply contrasted with the typical Keweenawan diabase that a separate name seems necessary." He found no indication of bedding like that seen in the diabase. He found the gabbro cut by intrusive granite, much of it being fine-grained and pinkish mixtures of orthoclase and quartz.

* There is a general description of this "alternation" on pp. 177—78, Vol. III, Geology of Wisconsin, where it appears that there was observed nothing more than an interrupted series of exposures of gabbro, with diabase intervening.

† Irving, Geology of Wisconsin, Vol. III, p. 171.

Irving put the gabbro in the Keweenawan for the following reasons. (Geol. Wis. Vol. III, pp. 171–172).

1st.—The close similarity it presents in mineral composition to the true Keweenawan diabase.

2nd.—The evident interstratification with the latter near the junction of the two.

3rd.—The manner in which unmistakable Keweenawan diabase fills the eastern extension of the gabbro belt in the vicinity of Montreal river.

4th.— The massiveness and apparent eruptive nature of the gabbro.

5th.—The occurrence of gabbros in the typical Keweenawan region of Keweenaw point, and with the typical Keweenawan diabase in Douglas county, Wisconsin.

6th.—The apparent non-conformity of the gabbro and the Huronian schists, as indicated by the way in which the junction line between the two cuts diagonally across the strike of the Huronian beds.

In the description of these gabbros both labradorite and anorthite are mentioned as constituting the feldspar ingredient, and the augite is sometimes laminated and sometimes nearly unchanged. One field exposure is described as "light-gray, often nearly white gabbro, a peculiar phase not noted elsewhere. Under the microscope the large plagioclases make up nearly the whole section." Indeed both he and Pumpelly refer in several instances to the exceeding coarseness of the plagioclase crystals, and the great preponderance of the feldspar over all the other constituents of the rock.

The third annual report of the director of the United States geological survey contains a somewhat later (1883) exposition of the Keweenawan by Prof. Irving, embracing some new field observations and some new lithological studies. Here he still retains the gabbro series, whether in Wisconsin or in Minnesota, in the Keweenawan; announces a new variety of the gabbro series from Minnesota, viz.: "anorthite rock." which he says is "merely a coarse gabbro, in which all the ingredients but the feldspar are wanting," (p. 97) and gives some of *the details of an unconformity of the gabbro series below the diabases of the rest of the formation,* in the Bad river region. This passage is so important that it is worth quoting in full:

"On Bad river, eighteen miles southwest of the Montreal, the lower division [*i. e.* the bedded diabases] has a surface width, from the Huronian slates below to the sandstones of the upper

division, of only 17,000 feet. Since the dip here is perpendicular, or nearly so, the thickness is not much less than this. It is shown, in the original memoir [Monograph V, U. S. Geol. Survey], that this extraordinary thinning is connected with the presence below of a great belt of the coarse gabbro described in a preceding paragraph of this chapter. This coarse gabbro —whether with or without interbedded fine-grained beds is not now known—usurps most of the thickness, leaving only some 5,000 feet for the usual thin-bedded flows of the lower division. The explanation may be that, early in the history of the series there was poured out here an immense thickness of a rock which solidified into the coarse gabbro, while later in its growth the vents were removed from here to either side. The coarse gabbro mass must have stood up to a great hight, and the later flows terminated against it on either side until they had accumulated sufficiently to overflow its upper surface," (pp. 136-7). On page 134, also, Prof. Irving speaks of these coarse gray gabbros, stating that they "present the appearance of a certain sort of unconformity with the overlying beds."

It appears from this that professor Irving was not willing to state unqualifiedly that the gabbro and the diabase were interbedded in the Bad river region. It also appears that in the same region the same relation of non-conformity obtains as in Minnesota, although its significance was not fully entertained by Irving. Thus Irving saw some of the evidences adduced by Dr. Lawson for considering the gabbro rocks of Wisconsin and Minnesota as constituting a formation intermediate between the diabase phase of the Keweenawan and the formation which he styled Huronian, which latter is a far older terrane, being, undoubtedly, one of the series which we now know as Ontarian, and probably the lower. It was owing to Prof. Irving's confusion of rocks of several distinct horizons under the general term Huronian that he fell into the error of putting the gabbro into the Keweenawan, an error that has vitiated the work of some of his associates, and that of some of his followers, and which projected itself into the geology of Minnesota. Whereas he saw the gabbros overlying and traversing the strike of the "Huronian" (Ontarian) in the region west from Bad river Wisconsin, he inferred, they must be later in date. Again, when he found the "Huronian"(Animike) associated with rock "identical with the Duluth gabbro," on Pigeon point, in a manner not readily determined, he applied the conclusions of

the former observation, and was moved to place the gabbro above the Animikie, at the base of the Keweenawan, although there is at that point no evidence whatever looking in that direction. Had he understood how much lower in the stratigraphic scale the Bad river "Huronian" is than the "Huronian" with which he compared it in other parts of Wisconsin and in Minnesota, he would probably have given due heed to both of the unconformities which he briefly notes, and would have retained the gabbro in that stratigraphic position, where for some reasons he had felt inclined to put it.

It is, perhaps, due largely to the researches of professor Irving that the application of the term gabbro in the Northwest was extended beyond the rocks that possess the petrographic characters at first included under it by Kloos and Streng, and by Pumpelly. Irving found all conditions of change in the augite toward diallage, and all conditions from diallage to chlorite.* The chief distinction between the gabbro and the diabases of the "lower division" of his Keweenawan consisted in outward structural features, and in visible petrographic characters. The gabbro is unbedded; the diabases always evidently bedded. The gabbro is generally light-colored and coarse-grained, never amygdaloidal, the diabases are dark, fine-grained and frequently amygdaloidal. Although he maintained that the gabbro was extravasated as a surface flow, and "cannot have been intrusive", yet he noted many of the evidences that disagree with that view. In short, structurally and petrographically the gabbro, in all respects, was thought to grade into the Keweenawan. This view was announced in his Wisconsin reports, and his later work for the United States Geological Survey does not vary in any of its main results, from the conclusions of the Wisconsin reports.

When we look into the reports of the Minnesota survey we find the term gabbro applied to the Duluth rock first in 1879 (published in 1880), at page 23. The present writer began a preliminary microscopical examination of a series of rocks collected by the survey, mainly along the shore of lake Superior, and in August, 1881, he read a paper before the American Association for the Advancement of Science, † in which this rock is referred to, but is included in the Cupriferous series. This was based on field examinations conducted in 1878 and 1879.

* Third annual report of the director of the United State Geological Survey, p. 102.
† Cincinnati meeting, p. 160. Tenth Annual Report, Minnesota Survey, p. 137.

As noted by Dr. Lawson (p. 14) the gabbro and feldspar rock at Beaver bay and about Split-rock point were referred, contrary to the opinion of Norwood, to a date older than the traps forming the shore. "Large masses of feldspar rock, embraced in the trap, as boulders are embraced in hardpan clay, have been carried from Carlton's peak, or from a range of hills north and west of it, toward the east and southeast. These embraced pieces become smaller in going from their place of origin, in the same manner as fragments of rock acted on by the drift forces." (Seventh Minnesota report, pp. 12-13). It was stated that the "feldspar rock" and the gabbro at Duluth are of one and the same formation, this statement being based on the existence, in minute quantities, not only of all the gabbro ingredients in even the feldspar masses, but the existence in the pudding-stones where the feldspar masses prevail of some rounded gabbro masses showing various degrees of transition to pure feldspar, the augite and magnetite being evident to the unaided eye, the former frequently chloritic. The writer had also examined the gabbro range at points remote from the coast line, and had expressed a similar conclusion. The following is from the tenth annual report, p. 80:

"The mineral composition, however, is constant, and allies it to the igneous rocks of the 'gabbro range' which graduate into the trap rocks of the Cupriferous. It seems, however, that there was a vast outflow of igneous rock in the midst of the era of the quartzyte and slate group producing this area of the gabbro range, and separating the lower portion from the era of the porphyries and the red shale and the red sandstone which are characteristic of the Cupriferous formation proper. There are some reasons for believing that this great igneous outflow entered the sedimentaries as laccolites in many places and thus tilted and modified the overlying beds, instead of being produced prior to their deposition."

Again on page 99, tenth report:

"On the south side of Little Saganaga lake the rock weathers white. It rises in higher bluffs, resembling the Rice point gabbro, and even approaching the whiteness and nearly the purity of the so-called 'feldspar rock'. It is mainly of feldspar, but also contains magnetite and a little pyroxene. The hills and ridges in general show a coarse bedding which dips south. Ridges 10 to 50 feet high. The sample collected is weathered. * * * * A pinkish-red vein of syenite, 20 inches wide, cuts this gabbro. It is comparable to the red syenite

associated with the gabbro at Rice's point. In both places it penetrates irregularly through the gabbro. * * * * This formation not only seems to be the 'Rice Point granite', and the iron-bearing rock of Mayhew lake, but also to have furnished ihe feldspar masses of Castle Danger and Beaver bay."

After an interval of several years during which these rocks were not studied by the Minnesota survey, but during which the last results of Prof. Irving's work on them were published by the United States Geological Survey, the attention of the Minnesota geologists was again directed to them. While Prof. Irving's large volume (Monograph v. of the U. S. Geological Survey) serves as a valuable systematic presentation of the geology of the "Keweenawan" as known to him through his studies for the Wisconsin survey, much of it greatly amplified by more extensive travels, and more extended petrographical study, yet its conclusions do not depart, in any important respect, from those published several years earlier by the state survey. He admits himself that he was only able to add two new varieties of rock worthy of names to the classification adopted before, viz: anorthite-rock and diabase porphyryte, and, near the close of his investigations, resuming the examination of the former, evidently after the volume had been printed, he found that the feldspar from which the name of the rock had been taken, "does not correspond in composition to typical anorthite," but rather resembles that of labradorite.* It soon became evident that there was something yet unknown, relative to the gabbro belt, in respect to its date and its stratigraphic relations with the rocks with which it was most frequently associated. It has been a standing problem that has presented itself obtrusively before us for about eight years. Owing to the discovery of gabbro interbedded with the Pewabic quartzyte in 1887 (16th report, p. 85), and alternating with it in great belts running east and west, having a common dip and strike,† and influenced by the prevalent notion that the successive sheets of the Cupriferous were essentially surface eruptions, we reached the inference that the epoch of the gabbro was that of the Pewabic quartzyte, and hence that the gabbro must be below the body of the Animikie. It should be mentioned, also, that a mistaken idea was held at first respect-

*Copper-bearing rocks of Lake Superior, page 438.

†This has been more fully demonstrated since then by the observations of Mr. U. S. Grant.

ing the place of this quartzyte with respect to the Animikie. It was due to observations made at and east of Wauswaugoning bay, on the lake Superior shore, in 1879, that this quartzyte, then styled Wauswaugoning quartzyte, was considered to be above the body of the Animikie slates; when, however, the Pewabic quartzyte was found to belong below those slates, and to carry the gabbro with it, there was no alternative but to separate the gabbro from the Cupriferous by allowing the interposition of the Animikie between it and the diabases, which characteristically mark the lower Keweenawan. Only remarking that later studies have tended to show that the Wauswaugoning quartzyte, with its slaty quartztytes, is probably on the same horizon as the Pewabic quartzyte, it will only be necessary here to introduce a quotation from the Seventeenth Annual Report (p. 52) to show the situation in this stage of the inquiry.

"Beds of gabbro are evenly spread with quartzyte strata above and below them, in the Pewabic quartzyte in northeastern Minnesota. In general the gabbro lies on the Animikie (Taconic) in Minnesota, but a favorable observation made at Chub (Akeley) lake demonstrates that this quartzyte was partially deposited over the Animikie before the great gabbro flood occurred. The usual immediate overlie of the gabbro on the beds of the Taconic is due to the fact that those beds were nearer adjacent at the points of issue of the molten rock." * * * * "It has been difficult to affirm, until recently, the age of the gabbro outflow. It has generally been considered to have followed the Animikie (Taconic), but that it was later than the commencement of the Potsdam (Pewabic) was not known to the writer till he made the observations referred to above," (p 54).

The idea that this quartzyte lies above the Animikie was of but short duration. In the eighteenth annual report is a general discussion of the "Age of the Gabbro" (pp 43-47) opening with these words:

"In attempting to correlate these observations with those that have been made and recorded in previous years, there is some difficulty in fixing the stratigraphic place of the gabbro eruption. It was inferred by the Wisconsin geologists that the gabbro sheet was the bottom layer of the great Cupriferous formation or Keweenawan, and this was accepted and has been followed unquestioningly by the writer in all previous reports and discussions of the crystalline rocks of the state. The age

of the great Cupriferous formation, with its traps and conglomerates, in part at least, has been established, with increasing evidence and positiveness as on the horizon of the typical New York Potsdam—at least at the horizon of a quartzyte which overlies the Animikie of the Northwest. Thus the gabbro sheet was carried to the same age. When the gabbro was found to be interbedded with a quartzyte in northeastern Minnesota, and to lie upon and overwhelm it (the Pewabic quartzyte), it was a necessary inference that that quartzyte was the equivalent of the Potsdam—or at least of the bottom quartzyte of the Cupriferous—and hence must lie over the Animikie, although at no place could the Animikie be seen interposed between it and the gneisses of the Giant's range. When it was found that this quartzyte, which is the principal iron horizon of the Mesabi range, shows evidence, in the region eastward from Pekegama falls, of passing below the body of the Animikie strata, necessarily carrying with it the gabbro sheet, the idea that the gabbro has possibly been put into a wrong position, is brought out prominently before the student of northwestern stratigraphy, and he is disposed to call in question the datum from which some important conclusions have been drawn."

In brief, the following considerations then were summarized for questioning the view that had hitherto been accepted, the same being indications that the gabbro lies below the Animikie and that the Keweenawan series, in its full scope, embraces not only its sandstones and diabases, so well known, but also the underlying Animikie. This view was not a little strengthened by the discovery, reported by Dr. A. C. Lawson *of metallic copper in the Animikie rocks in the Thunder bay district, associated with an amygdaloidal dyke of trap.

1. "The most important and significant fact that bears on the stratigraphic position of the gabbro, respecting its relation to the Animike black slates, is its occurrence along a wide extent, reaching from Gunflint lake southwestward as far as to the railroad crossing at Mallmann's (at least), *next to and immediately south* either of the gneiss of the Giant's range or of the "greenstones" of the Kawishiwin, without the appearance of any of the black slates between them. There is an appearance of *quartzyte*, with olivine grains and with magnetite, geographically between the gneiss and the gabbro, the same being unquestionably the Pewabic quartzyte seen near Gunflint lake.

*American Geologist, March, 1890, vol. v. p. 174.

This quartzyte sometimes is impure and limonitic, and seems to be the chief iron horizon of the Mesabi range. This near conjunction (which is sometimes apparently an exact contact) of the gabbro with the gneiss, and the absence of the Animike proper between them, has been supposed to be due to a local overlap of the gabbro beyond the strike of the Animike, covering it from sight, the idea being that the gabbro flowed back northward over older formations, and came on to the gneiss.

2. Although there has not yet been any careful microscopical examination into the differences between the typical gabbro (for instance that seen at Rice's point, near Duluth) and the eruptive rocks that overlie the Animike black slates at Gunflint lake and eastward to Pigeon point, it has been noticed that there are microscopic distinctions which ought to be explained in case of a supposed parallelism of one rock with the other. The supposition has been that they are stratigraphically and chronologically the same, and that the differences were only local and unimportant. It was this assumed parallelism and the evidently later age of the eastern outcrops (the "crowning overflow" of the Animike) which has led to the placing of the gabbro later than the Animike. There is absolutely no other evidence. If these two eruptive rocks are not contemporary, there is not only no reason against, but considerable evidence in favor of placing the typical gabbro (such as at Rice's point, and at Little Saganaga lake) below the body of the black slates.

3. Boulders of characteristic gabbro and of red syenite, and of the quartz porphyry, occur abundantly in the later "traps" of the Cupriferous. The quartz-porphyry pebbles are so abundant as to constitute the well known thick beds of coarse conglomerate; and quartz-porphyry layers or lenticular *sheets* are interbedded between the trap sheets. This quartz-porphyry in some cases appears to have originated in its present condition of interleaved sheets during the time of the Cupriferous. This is observable at the mouth of Baptism river, and at the Great Palisades. At these points, however, owing to the proximity of bosses of gabbro rising above the rest of the country about, it is certain that those portions of the Cupriferous, which contain the original quartz-porphyry beds, are near the bottom of the formation. This is further shown by the existance, in the same region (at and near Beaver Bay), of large boulder-masses of gabbro in the trap flows, evidently derived from the neighboring gabbro hills. From this point, northward to the gneiss of the Giant's range, nothing is visible, in

the form of rock *in situ*, except gabbro, or some "muscovado"-like rock described at some outcrops somewhat further west* by H. V. Winchell. The region is not fully explored, but it appears from all that is known, that there is nothing to be found of the typical, thin black slates of the Animike. It is as reasonable to infer that they followed after the gabbro flood, as that they preceded it. In case they followed after it, their typical characters were destroyed in this region by the frequent outbursts of igneous eruption, and they blended with the tuffs and shales and basic sheets that constitute, on the north shore of lake Superior, the lower portion of the Cupriferous formation. In case they preceded they must exist buried below the gabbro, as hitherto supposed. * * * *

5. On the supposition that the Animike black slates are involved in the Keweenawan, and, while overlying the gabbro, lose their typical characters at points further southwest, the interbedding of the Animike with beds of trap-rock, which is a common feature about Gunflint lake and on the shores of Loon lake, is easily explained, and indeed falls into place as one of the to-be expected facts of such a period of recurring eruptions. It also obviates the necessity of a supposed change in the character of the eruptive rock, *i. e.*, that the gabbro of Rice's point and Little Saganaga lake becomes, on Pigeon river, the dark or greenish trap-rock and the dioryte which inter-bed and characteristically overlie the Animike, forming the well-known 'crowning overflow' of that region."

Again, in "The Iron Ores of Minnesota," there are some considerations touching the nature and date of the gabbro disturbance.†

"The rock itself is gabbro, a basic eruptive, of gray color and generally of coarse crystalline texture. Its minerals are labradorite, augite, magnetite, biotite, olivine. The relative amounts of these minerals undergo great variation. While perhaps in no case will any of them be found entirely wanting over large areas, they are severally sometimes so scarce, while at the same places some of the others prevail, that the rock takes on very contrary aspects. When the labradorite prevails, as about Little Saganaga lake, and Bellisima lake, and in Carlton's peak, and in the feldspar masses that are embraced in the dark trap at Beaver bay, the rock when fresh is glassy,

*Seventeenth report, p. 90.91, Samples 387 (H).

†The Iron Ores of Minnesota. Bulletin VI. Minnesota Geological and Natural History Survey, 1891, p. 123.

gray, and firm, but on weathering it becomes almost white. When the magnetite prevails, as in the suburbs of Duluth, about the southern environs of Birch lake, at Iron (Mayhew) lake, and many other places, the rock is black and firm, and simply becomes speckled with lighter spots on weathering, the spots indicating the existence of crumbling crystals of labradorite. When the olivine or augite or both prevail, which is apt to be accompanied by the appearance of crystalline masses of hornblende, and in cases of weathering near the water, the rock has a green, or dark green color, the green tint being increased by the conversion through weathering of some of these into serpentine, chlorite or delessite. * * * It was supposed by the geologists of the late Wisconsin geological survey that the gabbro eruption in the main, took place after the completion of the Animikie strata, and that it formed the base of the Keweenawan, fading off upwardly by a succession of traps and sandstones and with interbeddings of conglomerates and volcanic tuffs into the most characteristic features of the Keweenawan. This view has also been held by all the Minnesota reports except the eighteenth. But it has been found that the great gabbro flood of northeastern Minnesota was outpoured at an earlier date. In the sixteenth annual report* will be found evidence that it began during the deposition of the Pewabic quartzyte * * * and must follow it to the lower portion of the Animikie, and hence to near the commencement of the Taconic."

On the geological map which accompanies "The Iron Ores of Minnesota," the gabbro belt is roughly laid off and represented as a distinct terrane separate from the diabases and conglomerates of the Cupriferous proper, under the name *Norian.* By an omission in the "transfer" by the lithographer the Carlton's peak area was not represented as Norian, although the Beaver Bay area of feldspar rock was included. This separated part was designed to include also all the red syenites, diorytes and felsytes with which the gabbro rock is closely associated. In thus removing large masses of crystalline rock, usually considered to be portions of the Archæan from the Keweenawan, it was not intended to convey the idea that they should be placed in the Archæan. It had been a growing impression, and had reached almost a conviction, resulting from an attempt to compare and adjust the results of study on these rocks in Minnesota with the published results of the Wisconsin survey, that

ages 85, 88; 17th report, pp. 52, 53; 18th report, pp. 43-47.

there was a great series of crystalline rocks, later than the Ontarian of the Archæan, of which there had not been made any just and correct interpretation. Sometimes these rocks have been studied in the field in Michigan and Wisconsin, and they had been put either in the "Huronian", that catch-all which covers much geological ignorance, and sometimes they had been included in the Keweenawan. It was quite evident also that the earlier geologists of New York and Canada had included them in the Laurentian, or in the upper Laurentian, sometimes designating them as "upper gneisses". At no place has it been appropriate to fully discuss this question in the publicatious of the geological survey. The bare announcement was made in the above mentioned map, because it was necessary to express something in the form of a "classification", of the iron-bearing rocks, but the reasons therefor were not given, as noted by Dr. Lawson. The first expression of doubt as to the correctness of this idea of their Laurentian age in Minnesota was in the following words, found in the ninth annual report of the Minnesota survey, p. 387.*

"The mineralogical characters of these belts of igneous rock, which form some of the main features of the topography, seem to ally them to the Norian rocks of T. S. Hunt, and to the labradorite rocks of Canada. At least, if they be not the western extension of those formations, then those formations have not yet been discovered in Minnesota. But several traverses have been made of the country northwest of lake Superior for the purpose of geological examinations without finding anything that is at all comparable to those formations if it be not the rock of these hill-ranges. The rock consists generally, of some feldspar, which at Duluth has been found to be labradorite in large per cent., and at some places constituting over ninety per cent. of the mass, with varying proportions of augite or of magnetite, or magnetic menacannite, with various accessory ingredients, or of minerals that result from change. It is massive, firm, usually dark colored, and rises in low mountain ranges, as already stated. * * *

So far as examined these labradorite rocks contain no bands of limestone. In the absence of this element, and in this only, so far as can be judged by the writer, these labradorite rocks seem to differ from the labradorite rocks of the 'upper Laurentian' of Canada." These rocks being, therefore, in Minne-

* Also in the Proceedings of the American Association for the advancement of science, 1880. *The Cupriferous series in Minnesota.*

sota, considerably younger than the Laurentian, there was thought to be good reason for suggesting that the *Eozoon canadense*, characteristic, as supposed, of the upper Laurentian in Canada, "may be instead an organism of Cambrian or lower Silurian."

Notwithstanding this and other expressions of similar purport, scattered through the reports of the Minnesota survey, it was not until the publication of the "Iron Ores of Minnesota" that any attempt was made to give general expression to a conclusion, and in that case it was without basing it on any discussion or putting forward of the data on which it might be based. Indeed, whatever the age of the *Norian*, so-called in Minnesota, there was no intention, even at that time, to separate it from the formation long known as Cupriferous, and later as Nipigon, or Keweenawan. But it was expected to retain it within that formation by some internal reconstruction of its stratigraphic components, or by an enlargement of its stratigraphic compass. It was suggested, in line with this purpose, that perhaps the Animikie disappeared from view between Pigeon point and Beaver bay, because of a change in the characters of the cotemporary sedimentation, by the action of which its characteristic slates and quartzytes were replaced at the same horizon by red shales, tuffs, sandstones and conglomerates, such as prevail along the lake Superior shore westward from Grand Marais. Such a transition at the horizon of the Animikie would make it necessary to include the Animikie in the Cupriferous, and would remove the obstacles which otherwise existed to the retention of the Norian, or gabbro belt, at a horizon below the Animikie, or near its base. It is to the discernment of Dr. Lawson that we are indebted for the first sufficient exposition of the relations of the characteristic Cupriferous to these gabbro rocks, put all together in a systematic discussion, with vivid illustrations. The writer has no hesitation in adopting the results of Dr. Lawson's work, for he regards them not only as well founded, but as a very welcome solution to a very perplexing series of facts which needed and had not yet received any satisfactory adjustment.

There remain, however, one or two minor points which the careful reader will note, which need further consideration, inasmuch as this interpretation of Dr. Lawson's report carries its application to an extent somewhat further than he has himself

indicated, the important significance of which he may not have foreseen, or may not have been willing to accept if foreseen. These are:

1. Is the anorthosyte described by Dr. Lawson at Carlton peak, Beaver bay and Split-rock point, geographically a portion of the great gabbro belt, and identical with it in origin and date? This hinges very largely on the next.

2. Is the "anorthite rock" which characterizes the anorthosyte at Carlton peak and Split-rock point petrographically the same as the gabbro of the gabbro belt, only differing from it in non-essential characters?

The summary results attained by Dr. Lawson are made to apply by him only to the distinctive outcrops at Carlton peak, Beaver bay and Split-rock point. The region of the Duluth rock, where the gabbro of the Northwest was first known, and has been most studied, is omitted by him from his discussion. The same is true of points farther east, such as the gabbro of Hat point and of Pigeon point. He does not allude to outcrops in Wisconsin. His determinations require a rock made up entirely, or almost entirely, of anorthite or labradorite feldspar. The specimens he examined appear to have been such. Probably more field-work may be required to remore all doubt as to the continuity of the anorthite rock and the gabbro geographically, and more laboratory work to determine the petrographic characters that may ally or dissociate these rocks, but it may be well to summarize briefly the facts which seem at present to warrant the assumption that they are the same.

1. They have been described by professors Pumpelly and Irving, as can be seen by the foregoing quotations from their reports, in such terms that they cannot be separated into two formations either geographically or petrographically. In numerous instances they have described the gabbro, in its large and characteristic exposures in Wisconsin, as made up almost wholly of one feldspar, usually labradorite, and sometimes in very large grains or crystals.

2. When the present writer collected samples from the boulder-masses of feldspar rock embraced in diabase near Split-rock point, he was particular to note that some of the masses were not of pure feldspar rock, but contained, in the usual proportions, the minerals augite and magnetite. Thus he noted in the field, and subsequently published the alliance of these two rocks petrographically, the two embraced together heterogeneously in a sort of pudding-stone of trap-rock, to the

exclusion of every other kind of rock, except the red granite.* Since that time microscopical thin sections have revealed in the feldspar boulders, however pure they may appear to the eye, small quantities of augite, and from these minute quantities there are all gradations to typically constituted gabbro. There are also, amongst these detached masses, some that are darker than the ordinary gabbro, containing very large proportions of augite and magnetite, with some olivine.† It thus appears that at the *locus*, where the later diabase sheets received the distinctive anorthite rock, there were variations to typical gabbro, and even to the very dark and heavy gabbro. Such variations have been noted repeatedly at points where the gabbro belt appears in Wisconsin and in Minnesota. Again the red granite pieces, which appear as isolated boulders in the diabase flows at Beaver bay, indicate the same relation, for red granite, the augite-syenyte of Prof. Irving, is a frequent attendant of the gabbro range in Minnesota, as well as in Wisconsin.

The nicer distinctions between the feldspars, i. e. whether labradorite or anorthite, do not seem to play any important part in the solution of the question at issue. There is good authority for the statement that both these feldspars are found both in the anorthite rock and in the gabbro, although it now appears that labradorite predominates in both. This itself is a bond of petrographic alliance between them and is perhaps as strong as any.

Negatively considered, if the anorthite rock be not the same formation as the gabbro, room must be made for both of them in the geologic composition of the northern part of the state, and it will require a greater reconsideration and a greater reconstruction to accommodate two such formations than to accommodate one and implies greater error in all previous work.

The consequences of this important result are far-reaching. It makes it necessary to reconsider some of the descriptions that have been published of the relations of this rock to other formations, in Wisconsin, and also to make some comparisons with similar geology in regions further east.

The Bohemian mountains, of Keweenaw point, were described by Foster & Whitney‡ as constituting the axis of an anticlinal

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*See pp. 111, 112 and 113, Tenth Annual Report.

†One of the samples collected by the writer, numbered 816, shows this character. Another of the same number is nearly pure feldspar, but its grain is not so fresh and coarse as much of that seen at Beaver bay.

‡Report on the Geology and Topography of a portion of the lake Superior land district, Part 1. Copper lands, p. 64, 1850,

structure, which they gave to the point. The rock of this range was said to be different from that in the northern trap ranges, both in lithological character and in the mode of its occurrence. The northern range was made up of numerous trap beds, with amygdaloidal and granular varieties interstratified, and with various detrital rocks, especially conglomerates. The Bohemian, or southern range,. consisted of a vast crystalline mass, forming an anticlinal axis, "flanked on the north by the bedded trap and conglomerate, and on the south by conglomerate and sandstone." The contour of the bedded trap was observed to be very different from that of the unbedded. The hills composed of the former rise by a succession of stair-like ascents; those of the latter are either dome-shaped or rounded. The rock itself sometimes contains numerous crystals of magnetic iron ore which occasionally forms a large portion of the rock. The diagrammatic section given by Foster & Whitney (p. 66) shows Bohemian mount, "composed of labrador and chlorite," with its irregular patches of magnetite, forming a central range in the form of an anticline *from which the other rocks in unconformable overlie*, dip in opposite directions. Numerous geologists, including Jackson, Foster and Whitney, Whittlesey, T. S. Hunt, Gaujot, described the structure as anticlinal. Itappears that this structure is very similar to that found to obtain in Wisconsin and Minnesota, wherever these terranes exhibit their mutual relations, and it provokes the inquiry whether it may not be well to re-examine the geology of Keweenaw point with this question in view. Prof. Irving included these rocks all in one series, substantially conformable amongst themselves, under the term Keweenawan, but it appears more than probable that there is a profound break between the rocks of the Bohemian range and the well-known traps of the northern range, and that too much was embraced under the name Keweenawan.

THE NORIAN.

The foregoing descriptions lead irresistibly to a search for a suitable name for the lower series. Precedent and scientific nomenclature seem to require the use of an old name if it be found that one has already been given to this group of rocks. Fortunately the dominant characters of this group are very marked, and they are easily found when they have been ascribed to any other locality. As we approach nearer a grand classification of the crystaline terranes, such as can be said to be applicable over large if not continental areas, it will become

necessary to abandon some of the local names which have been used during the course of investigation, and to choose from the various synonyms those which will be warranted by the rules of geological nomenclature. Mr. Lawson has proposed a new name (Carltonian) and that will be convenient for those who do not yet feel ready to accept the grander parallelisms, and who do not wish to confound their studies by the use of possibly ambiguous terms. But to the writer the field-study and the research have been pursued far enough to warrant the reference of these rocks to a recognized epochal position, with a well-known designation. At first called upper Laurentian, by Logan, because they lie unconformable on the real Laurentian rocks, north from Montreal; subsequently Labradorian, by T. Sterry Hunt, because of the prevalence of that mineral (labradorite) which received its name from Labrador; they were lastly designated, by the same geologist, Norian, because of their prevalence at Esmark, Norway, where the norytes were first described. The term "upper Laurentian" is objectionable because there is reason to believe these rocks are separated from the Laurentian by a long interval of time, and because their dominant characters show them to have been largely of a basic eruptive, and thus very markedly distinct in date and origin from the acidic granites and gneisses that characterize the proper Laurentian. Were it not for this the term "upper Laurentian," having precedence in date, might be perpetuated. Dr. Hunt was the author of both the other terms, and his later choice was Norian.* His succinct description of them is in the following terms:

"The typical norytes consist chiefly of a triclinic feldspar, varying in composition from anorthite to andesine, but generally near labradorite in composition. The color of these rocks is ordinarily some shade of blue,—from bluish-black or violet to bluish-gray, smoke-gray or lavender, more rarely passing into flesh-red, and occasionally greenish-blue, greenish, or bluish-white. The weathered surfaces are opaque white. These norytes are sometimes nearly pure feldspar, but often include small portions of hypersthene, pyroxene, or hornblende,—the former two being sometimes associated in the same specimen and in contact with each other. A black mica (biotite), red garnet, epidote, chrysolite, and menacannite (titanic iron) are frequently present in these rocks; quartz,

*Chemical and Geological essays, Third edition, 1891, p. 278. The term was also used by Hunt in the second edition p. 278, 1878.

however, is rarely seen, and then only in small quantities. Through an admixture of the first named minerals these norytes pass into hyperyte, diabase and dioryte. The norytes vary in texture, being sometimes coarsely granitoid, and at other times fine grained and nearly impalpable. The coarser varieties often present large cleavable masses showing the striæ characteristic of the polysynthetic macles of the triclinic feldspars, and sometimes exhibit a fine play of colors, as in the well-known specimens from Labrador. A gneissic structure is well marked in many of the less coarse-grained varieties of noryte, and the lines of bedding are shown by the arrrangement of the various foreign minerals. Although norytes predominate in the Norian series, they are found in the area of these rocks which is seen to the north of Montreal to be interstratified with beds of micaceous orthoclase gneiss, quartzyte and crystalline limestone."

Toward the south further these rocks prevail in the southern Adirondacks, appearing on lake Champlain. They contain in Essex county the titanic iron ore which has been mined for many years. They are here associated, in some manner as yet unascertained, with a large series of quartzose gneisses, crystalline limestone and hematite ores. In the northern slopes of the Adirondacks these latter rocks are very largely developed, dipping conspicuously toward the north, and northwest. A late examination by the writer convinced him that these gneisses do not belong in the true Laurentian, although usually so regarded.* In some of their outcrops they seem to pass lithologically into the quartzyte so largely wrought at Potsdam although no structural evidence was found to support such hypothesis. In many places, however, in eastern New York the norytes have been described as interbedded with such rocks, and in the Courtlandt series, on the Hudson river they embrace nonconformable masses and blocks both of quartzyte and of limestone known to be of primordial age by the discovery of characteristic trilobites. The series extends into New Jersey, carrying valuable iron ores, long mined, but there the mined ores are non-titanic magnetites. In the Courtlandt series, according to the descriptions of Prof. Geo. H. Williams† all transitions occur between the degree of presence or absence of the hornblendic, the augitic, the biotitic and the chrysolitic varieties. The olivine bearing portions are "destitute of any

*See, however, JAMES HALL, Am. Journ. Sci., (3), XXI, 298, who excludes them from the Laurentian.

†American Journal of Science (III), XXX, Jan. 1886, p. 27.

considerable quantity of feldspar, and belong therefore to the family of peridotytes". They pass, however, by an increase in the amount of feldspar, into olivine norytes, olivine gabbros, and olivine diorytes. "The constant occurrence of such transitional forms, and the want of any regularity in the distribution of the pure tpyes, make it impossible to regard these rocks as anything but local modifications, or special facies of one and the same mass. However great their mineralogical variety may be they together form but a single geological unit". The age of this invasion of the fragmentals at Courtlandt by basic irruptives is certainly paleozoic, on the authority of Prof. J. D. Dana;* and Prof. J. F. Kemp has stated that they contain (at Rosetown near Courtlandt) masses of Cambrian limestone. Dana, indeed, at first considered them metamorphosed sediments of Lower Silurian age, as there are various crystalline effects produced by them on the concerned clastics, resulting in schists and diorytes and soda-granites.

The same rocks have been found by C. H. Hitchcock in the White mountains of New Hampshire, and there they are said to lie non-conformably upon an older metamorphosed series, which again is non-conformable upon the true Laurentian.

A formation thus characterized and so easily identified by its lithology as well as its stratigraphic relations should not longer be without a recognized name; and it seems appropriate that it should bear the name Norian, whether it be found in the east or in the northwest. In Minnesota, and in the north west generally, wherever these rocks have been found they are associated with various evidences of upheaval, metamorphism and eruption. Therefore, they afford not only one, but numerous interesting features, which are as yet but faintly understood, giving rise to several problems, the true solution of which can be but partially foreshadowed, or are entirely beyond answer with our present knowledge.

THE LOGAN SILLS.

Professor Lawson's second paper, *the laccolitic sills of the Animikie rocks of lake Superior*, has a close relation with some of the problems alluded to above, and his investigation throws some light on them.

It had been, apparently, the source of some perplexity with Prof. Irving, that the gabbro, wherever he saw it in Wisconsin —and the same is true of it in Minnesota—is non-bedded, non-

*American Journal of Science, (III), XX, 194, 1880.

amygdaloidal, non-basaltic, never presenting the peculiar stair-like ascents up the hills which it forms, noted by Foster and Whitney as characteristic of the traps of Keweenaw point. In order to account for this, and for some other peculiarities of its distribution and manner of outcrop, he imagined that perhaps the gabbro bosses that now appear at the surface are simply the congealed and now uncovered reservoirs of basic rock material which furnished the diabasic overflows of the Cupriferous. This suggestion he repeats:

"The great coarseness of grain, the perfection of the crystallization, the abrupt terminations of the belts, the complete want of structure and the presence of intersecting areas of crystalline granitoid rocks—all suggest the possibility that we have here to do with masses which have solidified at great depths. They certainly cannot, however, be regarded as intrusives, so that unless we regard them as great outflows, we should be forced to look upon them as the now solidified reservoirs from which the ordinary Keweenawan flows have come."*

This hypothesis, though rejected by Irving, taken in connection with the facts adduced by Dr. Lawson and the further fact that there is no essential petrographic distinction between the gabbro and the diabases of the Keweenawan, but that attendant physical surroundings would account for all their differences, seems to explain many of the anomalies which hitherto have hung about the accepted theory of origination of the gabbro. In northeastern Minnesota the gabbro belt, along its northern border, crowds more and more toward the north. It successively traverses the southern surface boundary of the lower Animikie, or Pewabic quartzyte, with which it is conspicuously interbedded, then rests against or upon large areas of the Keewatin (or Kawishiwin) greenstone; and finally is absolutely in contact with granites and gneisses of the Giant's range, and then falls rapidly away southward. It has been supposed that as a surface flow the gabbro spread back northward and thus came into contact with these older rocks in the same manner as the Keweenawan diabases have been observed to do; but it may be that this movement was a deep-seated laccolitic motion of molten rock, entering such openings in the earth's crust as the incidents of fracture and upheaval presented. Such openings were liable to appear not only in the

*Third annual report of the director of the U. S. Geological survey, p. 125.

Animikie but also in the Keewatin, the line of fracture in the crust taking such a direction as the exigencies of pressure or of weakness required. Such fracture in Minnesota would appear to have been in a crescentic line with is concavity toward the southeast, somewhat more sharply curved than the present shore line of lake Superior. Starting from Duluth it ran rapidly north or northeastward. Then it turned more eastwardly, at a distance of about seventy miles from the lake shore; then still more southeastward, and reached the shore again at Pigeon point; there passing under the present water surface, reappearing apparently on the northern side of Isle Royale. Such fracture line, or at least such a gabbro belt, conforms with the line of outflow-points of the Keweenawan, and with the laccolitic appearances of the trap sills in the slates of the Animikie as well as with the greatest frequency of diabase dikes. It would be necessary to allow, on this hypothesis, that large thicknesses of rocky strata have been removed at the points where these gabbro reservoirs gathered, in order to explain their present appearance at the surface.

As to the date at which this laccolitic disturbance may be supposed to have taken place, it is plain that, if it gave rise to the surface flows of trap which characterize the Keweenawan, it must have been substantially cotemporary with the Keweenawan. The Animikie must have been deposited prior, and perhaps some of the Keweenawan. At any rate the escaping molten magma is interbedded with and constitutes some of the Keweenawan and is involved with some clastic beds. Wherever the Animikie existed it was liable to these intrusions. Where it did not exist the laccolites were formed in older rock. Where the batholitic gabbros are directly overlain, as at Carlton peak and at Beaver bay, by Keweenawan diabase it at first appears there was an interval of surface erosion between the intrusion of the massive gabbro and the extrusion of the bedded diabase. The massive structureless knobs of gabbro could not thus be formed at the surface by extrusion. At such points the Animikie may have once existed. That would require that the grand epoch of this disturbance should have its commencement prior to the bulk of the Animikie; should continue through it and should have its close in the later portion of Keweenawan time. If the Animikie never existed at such points, in order to produce such unconformities there must have been eroded some older rocks in order to expose the gabbro to the later trap outflows. Such older rocks must have been some of the

Archæan, and in that case some traces of them ought to be found at some of these interesting localities.

The non-existence of volcanic debris in this period of disturbance, when such deep-seated movements were taking place, allowing the transference of enormous quantities of molten rock from place to place within the crust, and the extrusion of other enormous quantities at the surface, and that, too, at a time when the presence of the sea about the vents is attested by the occurrence of interbedded clastic rocks, would certainly be an unexpected anomaly. Dr. Lawson has found nothing that indicates the existence of contemporary volcanoes in the Animikie, but such negative evidence is not quite sufficient to establish such an important principle. In this, however, while he agrees with Prof. Irving, who found no volcanic ash even in the Keweenawan, he is at variance with Foster and Whitney and with other observers, including the writer. It is very probable that the nature of some of the soft amygdaloids, and some of the stratiform clastic beds of the Keeweenawan have not been investigated sufficiently. It is very certain that some beds embraced between sheets of trap on the north shore of lake Superior, consisting of wholly non-consolidated materials, have the appearance of being of the nature of volcanic ash, but they have not yet been examined with care.

It is difficult therefore, with this interpretation of the gabbro intrusion, to separate structurally and chronologically the later diabase extrusions of the Cupriferous from the gabbro itself, just as it is to distinguish the one from the other by any essential petrographical characters. If this hypothesis be abandoned, and the gabbro belt and the anorthosyte rocks at the localities described by Dr. Lawson, be relegated wholly to Archæan time, as suggested by him, there will arise such attendant problems that it may be found impossible to satisfy all the facts. For instance, if the gabbro (anorthosyte) disturbance was in Archæan time, and the diabase outflows and the Animikie laccolites, were produced in paleozoic time, and hence subsequent to the basal Taconic erosion-interval, how does it happen that the gabbro (anorthosyte) rocks are interbedded with the Pewabic quartzyte which is the base of the paleozoic? How also can it be explained that where the gabbro (anorthosyte) intrusions approach the Animikie slates, forming large bosses such as Mt. Josephine and Pigeon point, there also the diabase dykes and laccolitic sills are found to be largest and most numerous? It may reasonably be asked

also, on the hypothesis that the gabbro (anorthosyte) rock is of Archæan age, how can its close petrographic alliance with the diabases be accounted for? Probably the chief obstacle to the separation of the gabbro (anorthosyte) rock from the epoch of the diabase extrusions, lies in the close areal agreements which they manifest. In general, the area of one is the home of the other. Wherever the gabbro occurs there is associated traprock, though the converse is obviously not true. The trend of the gabbro (anorthosyte) belt, whether in Wisconsin or Minnesota, conforms closely with the strike of the diabase belt. On the south side of lake Superior the gabbro (anorthosyte) belt is to the south of the northward dipping surface diabase flows; on the north side of the lake it is on the north side of the southward dipping diobase flows. In each case it allows the supposition that, on the degradation of the rocks covering the batholite while the reservoir was feeding the surface flows, the uncovered batholite is separated geographically from the diobase flows by a surface interval which *may be occupied* in whole or in part by some of the Animikie beds. This interval is frequently hid by drift accummulations and has rarely been studied with care. However, in any case, whether there be any intervening Animikie or not, if the intrusion of the gabbro took place within Archæan rocks at such places as where those rocks constituted a dry land surface, and the Animikie had never been deposited over them, the diabase extrusions would then lie directly upon the Archæan, and on being uncovered the gabbro would be found interbedded and otherwise in contact with the Archæan rocks.

There seems, however, to be no ready way to explain the immediate overlie of the diabases on the gabbro (anorthosyte) rocks, as described at Carlton peak and eastward from Beaver bay, and as mentioned by Prof. Irving in Wisconsin, and by Foster and Whitney on Keweenaw point, except by supposing two epochs of disturbance, allowing an erosion interval, or one long-continued epoch with a diversified history including surface degradation at such places. Dr. Lawson's illustrations and descriptions in this bulletin are perhaps the strongest evidence of such direct unconformable immediate superposition of the diabase upon the anorthosyte, *in situ*, but it is yet to be shown that those contacts are not rather upon detached masses of the anorthosyte rock. It is no uncommon thing to see masses of the anorthosyte fifteen or twenty feet in diameter wholly embraced in the diabase, and

in some instances they are two hundred feet. When numerous such masses are in juxtaposition it is plain that on exposure and glacial degradation they would present at the surface an appearance of continuous rock *in situ*. The lake shore line acting on such a mass would bring out the "serrated" coast noted by Dr. Lawson, and the individual masses would appear as knobs rising above the more rapidly destructible intervening diabase matrix. Such a deceptive appearance occurs at Duluth. It is the most obvious inference, based on casual examination, that at that place the melaphyrs and diabases lie immediately upon the gabbro; but between the actual outcrops of the two is an interval rather poorly exposed to observation, in which have been seen not only rounded masses of gabbro, detached from the main hill range, but also some rock of obscure characters greatly changed from its original and referable to some of the basal members of the Animikie.*

This indefinite rock in other places assumes large proportions and appears as the extensive "red rock" alternating with and cutting the gabbro and the anorthosyte rocks as at Rice's point, at Beaver bay, and at Pigeon point. It has been observed at many places to pass into a sedimentary rock. It is frequently plainly a conglomerate originally. This belt of changed Animikie appears to run with the gabbro from Duluth to Pigeon point. At the latter place Prof. W. S. Bayley has made a special study of the contact phenomena of the gabbro on the slates and quartzytes and his conclusions† lately published confirm those of Richard Owen and J. G. Norwood,‡ and of the writer published in many places, to the effect that the red rocks of the Cupriferous, including the quartz porphyries and red syenites specially, are modified conditions of sedimentary rocks. The persistence of this modified belt, giving rise to soda granites and augite syenites, or to "quartz keratophyres," referable to pre-existing (probably) Animikie strata, precludes the non-existence of the original Animikie strata throughout any wide extent between Duluth and Pigeon point, and looks toward their probable future discovery, perhaps in some of these disguised forms, in the vicinity of Beaver bay, and hence to the probably detached condition of the anorthosyte rocks on which the diabase flows are seen to lie at that place.

*Ninth annual report, p. 11, under "1 D;" p. 12, under "7;" p. 17, under "42;" tenth report, pp. 107-109, under "807" and "808."

† Am. Jour. Sci. XXXIX, 273, 1890.

‡ Report of a Geological Survey of Wisconsin, Iowa and Minnesota, D. D. Owen.

The existence of this extensive "red formation," so closely an attendant upon the gabbro belt, is suggestive of still another hypothesis. Briefly the characters of this rock may be summarized. It is, speaking broadly, a rock of orthoclase, hornblende and quartz. The predominating orthoclase is sometimes so coarsely crystalline as to be macroscopically evident, but is more frequently so indefinite as to show no crystalline texture, becoming felsitic. The coarser crystallization is found in the large bosses which sometimes make mountain-like hills and ranges. The finer sorts are seen as quartz-porphyries, felsytes, intersheeted with diabases or cutting them, and as veins in the gabbro. The feldspar is not wholly orthoclase, but is sometimes seen to be a striated plagioclase, which Prof. Irving considered oligoclase. Like all the other minerals the orthoclase is reddened by abundant ferric oxide. This has been considered a secondary product of alteration, but it is more likely to have been originally in the rock from which the "red rock" was derived. The ferro-magnesian mineral is usually hornblende, but Prof. Irving found that very often it is augitic. He inferred that the hornblende is wholly derived by alteration from original augite. It is very certain that it is sometimes chloritized. The quartz is the most interesting of all the minerals, as it assumes positions and forms which indicate its origin. In some cases it prevails over all the other ingredients, making a quartzose rock, which should receive rather the name gneiss. Prof. Bayley gives it on Pigeon point the name "quartz-keratophyre." Those grains of quartz which were in the original rock have undergone some molecular changes, but usually not enough, especially in the finer grained portions, to destroy their clastic characters. The "club-shaped" quartzes seem in the red augite-syenites associated with the gabbro at Duluth, were pronounced to be secondary quartz by Prof. Irving,* and that which had been so completely fused as to crystallize independently amongst the orthoclases, was considered by him as the original quartz. The reverse may be true, the original fragmental quartz grains having been drawn out into the forms which are illustrated, and some of them rearranged as to outward form, and all of them as to crystallographic directions. When complete fusion was superimposed on the sedimentary mass, the quartz grains were blended in one, and on cooling were forced to accommodate themselves to the adjoining orthoclases. In the felsytes the quartzes are sometimes in

*See particularly Mon. V, U. S. Geol Sur., Pl. XIV and the accompanying description.

semi-rounded grains and sometimes are doubly-terminated crystals. These rocks show almost every conceivable manner of association with the gabbro. They cut it in dikes, both perpendicular and inclined, and they swell out in large patches, surrounded by the gabbro. They underlie and overlie large areas of gabbro, and both are cut by the later dikes of diabase. They are cut off by perpendicular bosses of the gabbro, sometimes having a perpendicular or inclined line of close contact without blending, and sometimes the elements of the two rocks are united as by a mixture in one common magma, making them, apparently, the so-called orthoclase gabbro, as seen at Duluth. Considering the diabases of the early portion of the Keweenawan as derivatives from the gabbro batholites, these rocks when cutting and alternating with the diabases, may in like manner be considered as cotemporary derivatives of large batholites or other masses of red rock ready to enter any openings in the surrounding crust where they could find relief from the crustal pressure. As pebbles, they are more durable than those of gabbro, and they constitute large beds of conglomerate in the base of the copper-bearing rocks. They are found as transported blocks or boulders in association with transported blocks and boulders of the gabbro inclosed in the later traps, as already fully noted at Beaver bay, and about Encampment island.

Chemical Analyses of the Red Rock.—For purposes of further comparison the following table is compiled of such analyses as are at hand of this "red rock" formation:

I. From the west bluff at the entrance to Beaver bay harbor. Analysis by J. A. Dodge. Building stones of Minnesota. Vol. 1, of the final report, p. 198. Survey No. 124.

II. Rice point, red granite; by Prof. J. A. Dodge. Tenth annual report; p. 204, Sur. No. 1 B.

III. Another analysis of the same as II, Prof. J. A. Dodge. Thirteenth annual report, p. 100 (No. 148).

IV. Finely crystalline brown syenite; Duluth, J. A. Dodge. Geol. Sur. No. 7. Thirteenth report, p. 100 (No. 149).

V. Fine grained, reddish brown rock; Duluth, J. A. Dodge. No. 19 of the Geo. Sur. series. Thirteenth annual report, p. 100 (No. 150).

VI. "Streamed," light red, with translucent laminations and specks. London (near Duluth). J. A. Dodge. Thirteenth annual report p. 100 (No. 152). Geol. Sur. No. 68.

VII. Brick red, rather fragile, apparently gritty and subcrystalline. J. A. Dodge. About two miles east of the mouth of Passabika (Lester) river, near Duluth. Thirteenth annual report, p. 100 (No. 153).

VIII. Purplish red granite from the west bluff at the entrance to Beaver bay. J. A. Dodge. Another analysis of the same rock as No. I. Geo. Sur. No. 124. Thirteenth annual report, p. 100 (No. 155).

IX. Grayish-red felsitic rock, in the field taken to be a metamorphic quartzyte or quartzose shale, rather slaty, with interlaminations of "streams" of siliceous matter. J. A. Dodge. Thirteenth annual report, p. 100 (No. 156). Geol. Sur. No. 127. The analysis shows this rock to be nearly identical with VIII, with which it probably has a connection. They outcrop near adjacent, at the west side of Beaver bay.

X. Red granite from the third island below Beaver bay. J. A. Dodge. Thirteenth annual report, p. 100 (No. 157). Geol. Sur. No. 134.

XI. Rock of the bulk of the Great Palisades, a red quartz porphyry. J. A. Dodge. Thirteenth annual report, p. 100 (No. 158). Geol. Sur. No. 139.

XII. Red, laminated, or "streamed," at the base of the Great Palisades. J. A. Dodge. Thirteenth annual report, p. 100 (No. 159). Geol. Sur. No. 140.

XIII. The red rock at Grand Marais; furnishes the pebbles of the beach. J. A. Dodge. Thirteenth annual report, p. 100 (No. 162). Geol. Sur. No. 203.

XIV. Red rock from the first island northwest of Belle Rose island, south of Pigeon point. J. A. Dodge. Thirteenth annual report, p. 100 (No. 164). Geol. Sur. No. 285. This seems to be the augite syenite examined by Prof. Irving, from Brick island.

XV. Analysis of the powder of seven specimens of the granular varieties from Pigeon point; W. F. Hillebrand. Reported by Prof. W. S. Bayley. Am. Jour. Sci. (3), xxxvii, 59.

XVI. Powder of three of the quartz porphyries from Pigeon point; W. F. Hillebrand. Reported by Prof. W. S. Bayley. (A. J. Sci.)

XVII. For purposes of comparison this analysis was made of one of the associated clastic rocks. It is from a pinkish quartzyte at the head of Wauswaugoning bay, near Pigeon point, a rock which is found in immediate contact with the red rock and with the gabbro on Pigeon point. J. A. Dodge; thirteenth annual report, p. 100, (No. 163.) Geol. Sur. Series 262.

XVIII. This analysis was also made for comparison. It is of a red sandstone, or quartzyte, fine-grained, from the north side of Siskiwit point, Isle Royal, formerly quarried for building stone. J. A. Dodge; thirteenth report, p. 100 (No. 165). Geol, Sur. Series 555.

An inspection of this table of analyses will convince anyone not only that the red rock series is a geologic unit, extending from Duluth to Pigeon point, thus agreeeing with the result derived from field evidence, many times reported, and with microscopical examination, but that it is referable to a change of sedimentary rocks immediately adjoining the gabbro bosses, and in that also agreeing with the results of extended field studies, the most thorough of which are those of Prof. W. S. Bayley on Pigeon point.

It is therefore a legitimate inference that where this red rock is most abundant, there the gabbro acted most powerfully and profoundly on the strata concerned. The Animikie, therefore, must have been fused through that whole belt where this red rock prevails—that is, in all that region north and northeastward from Grand Marais, and also westward toward Beaver Bay, and finally to the vicinity of Duluth, through which the Animikie rocks ought to be found, unless some such unusual event supervened to cause their disappearance by converting them into this puzzling *red rock.*

It is not necessary here to dwell on the importance of such a result. The writer, as he pursues this review, becomes impressed with the probable correctnesss of this last hypothesis, and is constrained to adopt it as a working hypothesis for future research.

Lithologists have looked at the augite syenytes from the side of original fusion and eruption, and all their microscopic characters have been interpreted and defined in terms of modern petrography, which hardly yet may it be said to have recognized any other source for crystalline rocks. Hence in reading the descriptions of these rocks (as those by Irving) many ideas of genesis and alteration must be reversed. It is also difficult to distinguish fact from hypothetical presumption. Facts and presumption are expressed with equal positiveness—nay, sometimes presumption is made more positive than fact by the addition of adverbs and phrases that are intended to highten the author's assurance and exclude the reader's possible doubt, as if there were no possibility of error in the initial data.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII
$Si\ O_2$	71.81	75.78	66.36	53.71	57.50	73.72	65.56	71.15	71.99	73.28	76.68	69.66	73.58	73.91	72.42	74.00	81.86	75.19
$Ti\ O_2$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.40	.34	.....	.....
$Al_2\ O_3$	12.82	11 09	13.33	14.96	13.29	12.82	10.06	12.40	12.36	11.83	12.14	11.49	13.36	14.89	13.04	12.04	9 87	10.78
$Fe_2\ O_3$	6.02	2.09	7.89	14.45	11.62	2.51	14.40	5.21	4.99	4.61	3.16	3.95	3.78	2.27	.68	.78	1.44	4.01
$Fe\ O$	.....	.....	2.96	3.65	4.54	0.22	0.23	0.75	0.56	0.56	0.52	0.60	0.69	1.70	2.49	2.61	2.36	1.05
$Mn\ O$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.09	.05	.....	.....
$Ca\ O$	2.26	.86	2.14	3.35	6.12	1.70	0.96	1.90	0.85	1.04	0.25	2.64	0.81	0.27	.66	.85	0.46	2.36
$Ba\ O$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.15	.12	.....	.....
$Mg\ O$	0.56	.65	1.20	4.59	1.63	0.35	0.73	1.13	0.72	0.36	0.26	0.71	0.18	tr.	.58	.42	0.81	0.95
$K_2\ O$	1.92	1.06	3.05	0.56	0.80	2.40	2.88	2.40	2.45	4.50	3.53	1.08	2.48	2.78	4.97	4.33	0.45	0.93
$Na_2\ O$	2.51	6.43	2.63	1.40	1.85	2.70	2.25	1.70	0.99	1.66	1.06	1.15	2.42	2.64	3.44	3.47	1.61	1.93
$Li_2\ O$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	tr.	tr.	.....	.....
$H_2\ O$	.....	1.82	1.21	1.60	1.48	0.94	0.86	2.12	2.92	1.82	1.66	8.55	1.14	1.01	1.21	.86	1.43	1.42
$P_2\ O_5$	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.20	.06	.....	.....
Cl	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	tr.	tr.	.....	.....
Total....	97.90	99.78	100.77	98.27	98.83	97.36	97.93	98.81	97.83	99.66	99.26	99.83	98.44	99.47	100.37	99.93	100.29	98.62

If these red rocks are referable to the cause here supposed, viz: a secondary product by fusion of sedimentary rocks, it will be necessary to make profound changes in the methods and reasoning of some microscopical students. They must begin their study from the opposite end of the process. The microscope must reverse its line of pursuit, and search for cause where it has been accustomed to find effect. It must accept as *original features* some things that it has called secondary. "Secondary" silica, "corrosion," "alteration" and "dynamic effects," described in these and probably other rocks as results of change from an earlier completely crystalline condition, must be considered remnants of a former stratified sedimentary structure. The student must proceed from these data, and other more evident data indicating the original state of these rocks, to build up a rational theory of their development into crystalline masses. This is a great field yet unexplored and one of prophetic potentialities for the Archæan rocks.

There are various other and important questions that spring up in connection with this view of the geognosy of the northeastern portion of the state, some of which may be alluded to.

1. What was the source of the material which formed the gabbro batholites—was it deep seated or was it within the earth's super-crust?

2. What portion of this red rock is contemporary with the gabbro itself in origin, and what part is simply the protruding knobs of older Laurentian with which the basic rock happened to come in contact when it was seeking a place of equilibrium within the semi-plastic crust.

3. Has the Giant's range granite any relation of cause and effect with the gabbro? In other words, is the granite of the Giant's range a keratophyre, or is it to be associated with the Laurentian or due to re-crystalline sediments of the Keewatin?

4. What was the effect of the gabbro upon the older sedimentaries, particularly upon the fragmentals of volcanic origin found in the Keewatin?

These questions, if solved, would probably give rise to others, and so on in a limitless series. The student never finishes his pursuit by the capture of ultimate results. He is simply lured on by present quest—may be he may add to the sum of human knowledge. These, however, are some of the problems which will concern some future students of these terranes.

PLATE VI. FRONTISPIECE. Contact of upper surface of a trap sheet with overlying Animikie slates in the rock cutting at the old railway station, Water street, Port Arthur.

I

THE ANORTHOSYTES OF THE MINNESOTA SHORE OF LAKE SUPERIOR.

INTRODUCTION.

The Minnesota coast of lake Superior between Duluth and Grand Portage was mapped and described by Irving, *as exclusively occupied by formations of the Keweenian (Keweenawan) series, and his discussion of the geology of the coast is certainly the most systematic which has up to the present appeared. State Geologist Winchell had earlier made careful examinations along the same line of outcrop, and had placed on record a host of detailed observations †on the rocks of the coast, without, at that time expressing any final conclusions as to their stratigraphy and general relations. Quite recently, however, we have an expression of Prof. Winchell's views of the geology of the coast of Minnesota in the form of a map issued by the State Survey. ‡From this map we gather that Prof. Winchell is in accord with Irving as to the Keweenian age of that portion of the coast which lies between Duluth and Grand Marais excepting two small areas at Beaver bay and the vicinity of the Palisades; but differs from him in classing as "Norian" the rocks at Duluth, and the most of those between Grand Marais and Grand Portage, together with those of the small areas above mentioned at Beaver bay and the Palisades. This correlation of the Duluth gabbro and the black gabbros east of Grand Marais, together with the red granites, quartz-porphyries and red felsytes of the coast, as a set of formations equivalent to the Norian is a suggestion which the writer is not prepared to follow. As it is, however, simply an expression of opinion, not yet supported by the publication of the facts and arguments which influenced Prof. Winchell to its adoption, it calls for no criticism.

But it is the accordance of Winchell and Irving rather than their differences of opinion to which the writer desires to direct attention, in order to make clear the views which obtain in the literature of the subject, as to the absence on this coast of

*Copper-bearing Rocks of Lake Superior.—Monograph V. U. S. G. S. Cap. VII.

†Geol. and Nat. Hist. Survey of Minnesota 9th and 10th Annual Reports.

‡Geological map of the Iron Regions of Minnesota by N. H. Winchell, and H. V Winchell, 1890. Accompanying "Iron Ores of Minnesota."

rocks of any geological horizon other than the Keweenian, or than those classed by Winchell as Norian.‖ The proposition which the writer lays down in this paper is that he has discovered on the Minnesota coast a geological formation of strongly marked individuality, which is distinctly older than the Keweenian, and is separated from it by a period of profound erosion. This formation is in no way connected with the rocks classed by Winchell as Norian.‖ The rock of which this formation is composed has been described by both Winchell* and Irving,† and was also observed by Norwood.‡ Norwood and Winchell first called the rock "feldspar rock" and the latter named the feldspar of which it is composed labradorite, subsequently referring to the rock as "labradorite rock." Irving after a seemingly thorough examination§ of the feldspar determined it to be anorthite and referred to the formation as "anorthite rock." None of these observers seems to have appreciated the significance of the field evidence as to the true relations of the formation to the Keweenian, and indeed no discriminative effort of any kind has been made to separate it from the prevailing series of the coast.

It is the purpose of this paper to set forth those relations, and to establish, by clear and unequivocal evidence, the existence on this coast of a new geological horizon of much interest.

The fact that the rock has been variously named by the only investigators who have published descriptions of it renders it necessary that the evidence of its true petrographical character should be first passed in review, particularly as the rock is in itself an interesting type whose importance is not yet fully recognized in petrographical literature. Following the petrographical notes, will be given a brief account of the distribution of the formation along the coast, and this will be followed by a discussion of its relations to the Keweenian, and of its probable correlation as a pre Keweenian horizon.

PETROGRAPHICAL CHARACTERS.

Irving's description:—Irving's summary statement of the petrographical character of this formation is as follows: "At several points on the north or Minnesota shore of lake Super-

*Ninth Annual Report. Pp. 29, 30. Tenth Annual Report. p. 39.

†Copper-Bearing rocks of Lake Superior. p. 59-61; 438-440.

‡Report of a Geological Survey of Wisconsin, Iowa and Minnesota, by D. D. Owen. 1852. pp. 360, 361, 380.

‖These are some of the rocks classed by Winchell as Norian. [N. H. W.]

§*Loc. cit.*

ior, between the mouth of Splitrock river and the Great Palisades, and again in the high point near the mouth of Temperance river, known as Carlton peak, are to be seen exposures of a very coarse, light gray to colorless or white rock, occasionally with a faint greenish tinge. This is seen in thin sections to be composed exclusively or nearly so of anorthite feldspar. Often there is no other mineral present except in exceedingly minute inclusions and these are very sparse. In one section a few grains of altered olivine were noticed within the anorthite, and in two or three a little augite between the feldspar grains. The feldspar appears in every case to be anorthite. In no section did it show the peculiar arrangement of needle like inclusions met in European gabbros, and so common in the coarse gabbros of lake Superior, to which this rock is very nearly related."

Supplementary description:—This description requires to be both supplemented and modified. One of the most remarkable features of the rock is its extreme freshness. The constituent feldspar of the rock is never found in a decomposed condition, but presents on the contrary uniformly, in all parts of the formation, perfectly glassy and brilliant appearance.

Another remarkable characteristic of the rock as a formation is its massiveness and lack of structural planes of any kind except under some abnormal circumstances which will be more fully mentioned in the sequel. Even jointage may be said to be entirely absent. Occasionally the formation is traversed by one or more fissures locally, but these follow no law of direction and cannot be regarded as true jointage. There are few of the massive rocks of the lake Superior region so free from structural planes. There is no flow or gneissic structure, and the rock seems nowhere to have been subjected to forces which would tend to deform the mass, render it schistose or in any way induce the development of secondary structures of a mechanical nature.

The color of the weathered surface of the rock is prevailingly white or yellowish white. The surfaces are usually smooth in general, but minutely rough, showing often the solvent action of meteoric waters in the same way that marbles and limestones do, though in a less marked degree. The weathered layer is very thin, and the fresh glassy crystals are apparent through it. The color of the rock on fractured surfaces is usually as Irving described it, but there are also darker, greenish-gray facies.

The texture is prevailingly coarse, the cleavage faces on the constitutent feldspar being frequently half an inch in diameter (occasionally an inch) and ranging from that to one quarter of an inch. In some localities it takes on a finer texture, and would then be designated a medium grained rock. The structure of the rock is eminently allotriomorphic-granular throughout the entire formation. No porphyritic crystals are anywhere observable, and under the microscope no suggeston of idiomorphic forms could be detected.

The Constituent Feldspar—The rock is, as former observers have noted, composed almost wholly of a plagioclase feldspar. In the majority of thin sections no other mineral, except in the form of minute interpositions, is present, and in the few sections in which a ferro-magnesian silicate may be observed, it plays only an accessory rôle. This plagioclase is not, however, as Irving affirmed, always anorthite. Neither is it, as Winchell believed, always labradorite. In an attempt to reconcile the conflicting statements of these two geologists, the writer has discovered that some portions of the formation accord with Irving's determination and other portions with Winchell's; that both were probably right as regards the material which they subjected to examination, but that both erred in generalizing as to the uniform character of the feldspar throughout the formation. The determination of the feldspar by optical and chemical examination is rendered comparatively easy by its perfectly fresh condition, its pronounced cleavage, the constant presence of strongly marked, polysynthetic twinning, and by the ease with which material free from interpositions can be selected for analysis. These interpositions are not uniformly distributed, and owing to the glassy transparent character of the crystals, it is a simple matter to separate among small fragraments, pieces which are perfectly clear and vitreous from those which are more or less charged with inclusions. With such favorable material a portion of the rock formation was definitely determined to be composed of labradorite.

Optical Measurements:—For optical observations a number of thin sections were prepared strictly parallel to the basal pinacoid, and to the brachy pinacoid, and numbers of readings were taken for the extinction of adjacent twin lamellae. The following results were thus obtained, the figures given being the mean extinction for the two sets of slightly discordant readings on either side of the cross hair of the microscope. The cleav-

age fragments selected were taken from material collected on the shore near Encampment island and from Carlton peak.

Extinction Angle on O. P. (001)	Extinction Angle on ∞ P $\breve{\infty}$ (010)
8° 41′	21° 17′
9° 00′	21° 27′
9° 02′	21° 27′
9° 07′	22° 21′
9° 08′	23° 33′
9° 09′	25° 00′
9° 12′	
9° 18′	
9° 22′	
9° 55′	
10° 49′	
10° 57′	
11° 00′	

These results locate the feldspar in the plagioclase series somewhere between $Ab_3\ An_4$ and $Ab_1\ An_2$, and it may therefore without hesitation be designated a labradorite.

Confirmatory tests :—In order to confirm this conclusion the material from near Encampment island was subjected to further tests. A calculation based upon the extinction angles above recorded, showed that the composition of the feldspar was about $Ab_2\ An_3$ and the chemical composition was predicted for it as it is given in column I of the table of analyses. Carefully selected material was then analysed (by W. C. Blasdale, Fellow in Chemistry in the University of California) and the results obtained are given in the adjacent column, II. This analysis again establishes the labradorite character of the feldspar. Its specific gravity, as determined on glass-clear fragments with the aid of Klein's solution, is 2.702 which is in entire accordance with its optical and chemical character. The powdered mineral, moreover, is insoluble after prolonged boiling in hydrochloric acid, the powder being in apparently the same condition at the close of the operation as at the beginning. There is thus no doubt whatever as to the mineral being labradorite.

Rock composed of Labradorite :—No other feldspar than the one examined can be detected in the rock. Indeed the material selected for analysis was not from a single crystal but from crystals in various parts of the hand specimen. It is therefore believed that the whole rock at this place is composed of labradorite feldspar and that no anorthite is present. This

view is sustained by the results obtained for the specific gravity of the rock as a whole. Three fragments of the rock taken at random, and ranging in weight from three grammes to sixteen grammes were used. The three results were 2.702, 2.704 and 2.706. The mean of these, viz : 2.704, varies so little from that of pure labradorite, that, in the total absence of any lighter non-feldspathic minerals, it may be safely inferred that the rock is composed practically of one feldspar, viz: labradorite. A bulk analysis of the rock, made upon fragments taken at random, by Mr. Chas. Palache, Fellow in Mineralogy in the University of California, is given in column III of the table, and also demonstrates the fact that the rock as a whole has essentially the composition of labradorite.

Rock composed of Anorthite:—A specimen from another locality, viz: from the cave to the east of Split-rock point, was broken into small fragments and pure transparent vitreous feldspar was again selected for analysis. This was submitted to Prof. J. A. Dodge of the University of Minnesota, and the results of his analysis are given in column IV of the table. This analysis shows that the feldspar at this locality, though rather rich in silica, is essentially anorthite, the alkalies being very subordinate in amount, and this confirms the correctness of Irving's optical determinations of the feldspar of this rock from certain localities on this coast. Irving's analysis* of a specimen from a point two miles below Beaver Bay is given in column V, but the relative proportions of lime and soda, as well as the specific gravity, suggest that the feldspar examined is bytownite rather than anorthite.

Chemical Annlyses:—The following table gives the result of a few chemical analyses which have been made of these rocks and of their constituent feldspars,† together with two analyses quoted for comparison:

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	53.01	51.30	47.40	51.45	47.25	47.30	49.155
Al_2O_3..........	30.04	31.46	29.74	31.94	31.56	31.50	29.620
Fe_2O_3..........	....	....	....	Trace	....	1.85	1.152
FeO..........	....	....	1.94	....	2.29	....	....
CaO..........	12.37	12 20	13.30	14.31	15.39	14.88	15.309
MgO..........	....	....	.57	.27	.27	.93	.911
Na_2O..........	4.56	5.33	4.99	.85	2.52	1.22	2.914
K_2O..........	....	....	1.56	.21	.37	.38	.695
H_2O..........	....	.79	1.64	.68	.40	1.80	.730
Total........	99.98	....	101.14	99.71	100.05	99.86	100.486
SpG.	....	2.702	2.704	2.709	2.70	....	....

* Copper-bearing Rocks. Monograph V, U. S. G. S., p. 438.

† The thanks of the writer are here tendered to Prof. Dodge and to Messrs. Blasdale and Palache for kind assistance in making analyses.

I. Theoretical composition of labradorite Ab_2 An_3, the latter being the formula calculated for the constituent feldspar of the rock from near Encampment island, on the basis of optical measurements.

II. Analysis of the same feldspar.

III. Bulk analysis of the rock from near Encampment island.

IV. Analysis of constituent feldspar of the rock from cove east of Split-rock point.

V. Analysis of the rock from point two miles below Beaver Bay as given by Irving, Copper Bearing Rocks, page 438.

VI and VII. Two Analyses of bytownite, quoted by Teall, British Petrography, page 146.

The name Anorthosyte:—It is thus clear that the mineralogical composition of the rock is not strictly uniform and that both the names which have been applied to it as a rock formation are unfortunate. Neither "anorthite rock" nor "labradorite rock" is a correct designation for the rock as a whole; and if a more satisfactory and comprehensive designation can be found, both of these terms should be dropped. The essential and constant feature of the rock is that it is almost exclusively composed of an allotriomorphic-granular aggregate of basic plagioclase. Such rocks are not unknown to the writer. Large areas of them occur in eastern Canada, and he has met them in the field at Narodal in Norway, and in parts of northern New Jersey, and in the Rainy Lake region. Such rocks have not yet, however, received a satisfactory place in petograhical classifications. While considering the question of a designation for such rocks, the writer had occasion to consult with Prof. Frank Adams of McGill College, Montreal, who, from his long study of similar rocks in the so-called Norian series of Quebec, is probably our best authority in this branch of petrographical science. In this correspondence Prof. Adams informs the writer that he has now in the press a memoir on just such rocks as form the subject of this paper, treating them historically, petrographically, geologically and comparatively. In this memoir Prof. Adams will retain the old name "*anorthosite*" for the class of granular rocks composed of plagioclase to the practical exclusion of the ferromagnesian silicates. Such rocks are regarded by him as being at one end of the gabbro series, while at the other end are those granular rocks composed of ferromagnesian silicates almost to the exclusion of the plagioclases. The term anorthosyte

is therefore here adopted for the plagioclase rocks of the Minnesota coast, in accordance with the usage which will certainly be established by the publication of Prof. Adams' memoir.

Accessory Constituents of the Anorthosyte:—The only original mineral which can be discovered in the slides as a constituent of the granular aggregate, is a faint violet brown monoclinic pyroxene. It shows none of the lamellar structure of diallage, and is evidently a feebly ferriferous augite. This augite, as has been stated, plays a very subordinate rôle, and is found in two modes of occurrence which are not sharply separable:

(1) As minute irregularly shaped patches, usually somewhat triangular, filling a few interstital places between the large grains of plagioclase. These particles are usually of uniform orientation throughout and consist of a single individual crystal. (2) As more or less rounded or bleb-like inclusions within the plagioclase crystals. In the latter case the plagioclase sometimes shows, by its undulatory extinction in polarized light, an area of molecular tension encircling the crystal of augite. In both occurrences the augite may be charged with magnetite dust, but is often seen free from such inclusions. In some slides the augite is perfectly fresh and shows no decomposition whatever. In other cases there is observable a fibrous structure occupying a peripheral zone of varying width, the fibers being all parallel. In still other cases the augite has become greenish, due to the presence of flocculent chlorite, and in others the whole of the augite has passed over into a nest of scaly chlorite with, perhaps, some serpentine. In one instance a shred of green hornblende was observed on the periphery of a partially decomposed grain of augite, and is probably also a secondary product.

Interpositions:—The inclusions or interpositions in the plagioclase are of three general kinds: (1) Original mineral inclusion arranged in plates or rods parallel to definite crystallographic planes. (2) Original liquid and dust-like inclusions arranged in irregularly curving planes without reference to the crystal structure. (3) Secondary inclusions of red iron oxide in minute specks, arranged peripherally to the plagioclase or along the cracks which occasionally traverse it.

The interpositions of the first class illustrate in a very striking way the same phenomenon that has been described by Judd as due to the process of Schillerization. (See plate II, Fig. 1). The mineral plates when seen on edge are of nearly

PLATE. II. FIG. 1. Microphotograph of section of anorthosyte from near Encampment Island, showing original interpositions of augite in labradorite. $\times 28$.

PLATE. II. FIG. 2. Banded anorthosyte at the cove below Split-rock Point, Minnesota coast, Lake Superior. Two dykes of diabase cut the banded anorthosyte and appear to the left in the illustration.

uniform thickness but of varying length. They are not present in all slides, but when they occur they are prominent features of the section. They appear in all cases to lie parallel to the plane of the brachy-pinacoid, and thus between crossed nicols they appear in sections transverse to $\infty P \breve{\infty}$ as heavy bars or dashes arranged parallel to the twinning lamellæ of the albite law. In sections but slightly inclined to $\infty P \breve{\infty}$ the broad sides of the plates may be observed; but the breadth when thus seen is several times less than the length. The plates are lenticular in form. Mineralogically they appear to be identical with the augite above described. They may be compared in the same slide with the augite which occurs interstitially between the feldspars, and no essential difference can be detected, the color and refractive power being the same. In many cases, however, a single mineral plate appears to be made up of an aggregate of minute granules of augite. The plates are also frequently charged with granules of magnetite. The relation of the plates to the plagioclase is such as to suggest that they are original inclusions, the feldspar being quite fresh and the contact of the plates with plagioclase, when studied with high powers, being irregular in detail. It thus appears from their mineralogical character, and from the mode of their inclosure that they differ from schillerization products; and that they are original inclusions although presenting precisely the same appearance under the microscope as the schillerized minerals described by Judd.

The inclusions of the second class are abundant but usually very minute. They may be observed frequently congregated in crescent-shaped areas and in these cases the inclusions commonly are pear-shaped. Bubbles may rarely be seen but they are not apparently mobile. In almost all cases where these inclusions appear to traverse a crystal in bead like rows, these rows may, by careful focusing, be seen to be but the traces of planes. These planes are usually irregularly curved and intersect one another in all directions.

The inclusions of the third class are abundant only locally, and then they give a faint reddish tinge to the rock as may be seen in specimens from Carlton peak. They appear clearly to owe their origin to percolating media, since they are formed only on the periphery of the feldspar between neighboring grains, and along the cracks which traverse them. The color is a bright red and the inclusion is usually a minute irregular patch.

DISTRIBUTION AND MODE OF OCCURRENCE OF THE ANORTHOSYTE.

Two Modes of Occurrence:—Anorthosyte has been observed by the writer at several localities on the Minnesota coast between Encampment island and Carlton peak, a distance of 46 miles. Its occurrence seems to be limited to the middle third of the coast. The region inland from the coast is, however, largely a *terra incognita*, and the formation may have an extensive distribution in this region. Its occurrences are of two kinds. (1) Outcrops of ridges and rounded surfaces, *in situ*. (2) In the form of very abundant inclusions as boulders and blocks imbedded in the Keweenian lava flows. Both Winchell and Irving have referred to some of the localities where the rock is found, but as the writer is able to add to the list of these localities, and to give a somewhat fuller account of the mode of occurrence, he will give a brief statement of what is known in this regard, even at the risk of repeating earlier observations.

Occurrence Near Encampment Island:—In passing down the Minnesota coast from Duluth, the first locality at which the anorthosyte is met with, is at a cove on the shore about half a mile below Encampment island, probably in Sec. 6, Tp. 53, R. IX. The anorthosyte here occurs in the form of very numerous boulders and angular blocks imbedded in an amygdaloidal diabase-porphyryte, which forms one of the Keweenian flows. Many of the boulders are of immense size, and several project for more than half their dimensions from the matrix in which they lie. Plate I, Figs. 1 and 2, will give some idea of the aspect of these huge masses. Two of these boulders were found to measure 13x8 feet, and 18x6 feet in greatest cross-section. Besides the large masses, there are very many small boulders and blocks ranging down to about three inches in diameter. Some of the smaller blocks are evidently detached fragments of the larger ones; and several of the latter were seen which had been cracked and the fissures filled with diabase-porphyryte. The boulders are perfectly fresh, and their contact with the imbedding matrix may be observed with knife-edge precision. The rock surface where the boulders are enclosed, has been glaciated and is furrowed with deep grooves. The projection of the boulders four feet above the general surface of the country rock, both being grooved, is instructive evidence of the limitations of the erosive power of glacier action.


AEL Photo 1891

Vicinity of Split-rock point:—The second locality where the anorthosyte forms a prominent feature of the geology of the coast, is at Split-rock point, and at the bottom of the small cove immediately below the point. Here it is found in both the modes of occurrence above mentioned. The extremity of Split-rock point presents a very remarkable aspect. It is a sheer cliff rising vertically fifty or sixty feet above the surface of the water. This wall of rock affords a clean section of a great breccia. The volcanic rock which forms the point, a diabase-porphyryte, is studded with innumerable boulders and angular blocks of anorthosyte. The matrix being very dark and the included blocks whitish or yellowish, the contrast is pronounced. The size of the blocks ranges from a few inches to several feet in diameter. They are in some places congregated together and in others they lie isolated in the matrix.

Around the point to the east we find the anorthosyte in place on both sides of the cove. On the west side a mass a hundred yards or more in extent is exposed, and the diabase-porphyryte is clearly seen, both to traverse it in sharply defined dykes, and to mantle its upper surface in the form of a flow. Here also may be observed a structural and mineralogical differentiation of the anorthosyte, which is apparently quite local in its character, and which has been observed by the writer only at one other exposure. This differentiation is apparent in the form of dark bands, which traverse the mass and give it a bedded aspect, as is exhibited in the illustration, Plate II, Fig. 2. These bands are usually only a few inches thick, but may sometimes be as much as a foot across. They have at this locality a characteristic jagged appearance, owing to the fact that the band has frequently no simple line of demarkation separating it from the normal anorthosyte, but is interlocked with it by means of sharp, wedge-like prolongations or tongues, which are approximately parallel to the trend of the band. The dip of the planes of the banding is to the north-east at an angle of about sixty to seventy-five degrees. The banded rock is traversed by three small dykes of the diabase-porphyryte which have a nearly vertical attitude, and which are easily discriminated from the bands on the ground, although they do not appear very differently in the photograph from which the plate has been prepared. These bands are mineralogically different from the normal character of the main mass of the anorthosyte in having a considerable proportion of a dark ferro-magnesian constituent (augite) which is more or less decomposed. Under

the microscope, the rock which composes the bands is not otherwise different from the normal anorthsyte, and the plagioclase appears to be in no way affected chemically by the decomposition of the augite, although the rock exhibits a tendency to mechanical disintegration by the separation of the feldspar grains.

On the other side of the cove, secton 6, township 54, range 8, the anorthsyte is exposed in much greater mass. Here it emerges from beneath the Keweenian eruptives and stands out as a bold, bare ridge with somewhat rounded outline, rising to an elevation of about 200 feet. The section here presented is shown diagramatically in the sketch Fig. 1. The base of the anorthosyte ridge is flanked to the southeast by a mass of red, fine grained amygdaloidal fieldspar-porphyry; and this in turn is flanked lakeward by an amygdaloidal diabase porphyryte, in which lies imbedded a boulder of the anorthosyte.

Irving's views on the occurrence at Split-rock:—Irving's general note on the occurrence in the vicinity of Split-rock point indicates that he regarded the anorthosyte as an eruptive mass, although his own observations are in part quite inconsistent with this view.

He says:* "Near the middle of S. E. ¼ of Sec. 5, township 54, range 8 east, this gabbro (one of the Keweenian flows) is interrupted by a vertically placed mass of excessively coarse-grained anorthite rock [anorthosyte]. The cutting mass is from 50 to 75 feet wide and bears north and south. It shows on both sides of a little square-angled, rock walled bay, on the south point of which it rises as much as a hundred feet above the lake. On both sides of the cutting mass the black gabbro is filled with large angular masses of the same coarse anorthite rock. The included masses sometimes reach many tons in weight, and in some places predominate over the including gabbro, which then appears as if veining the coarser rock. At the west angle of the bay the included masses are nearly absent and the gabbro resumes its usual vertically columnar appearance. At the north angle of the bay the anorthite rock rises again to a hight of over 150 feet. The inclusions of angular masses of the anorthite rock in the gabbro indicate the more recent origin of the latter, and this conclusion is borne out by the section made from a specimen taken at the contact with

*Copper bearing Rocks Monograph V U. S. G. S. page 302.

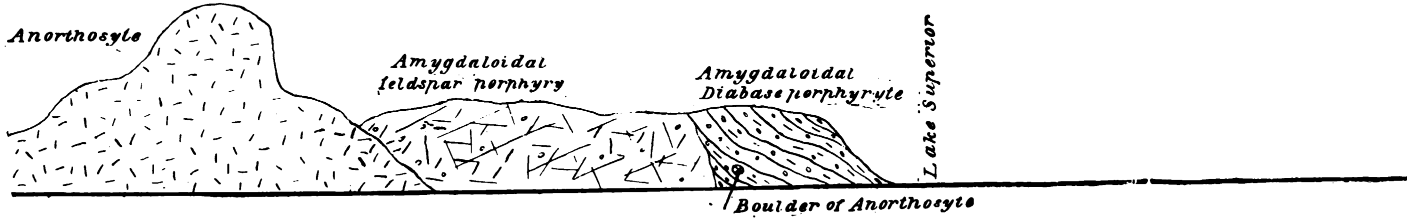
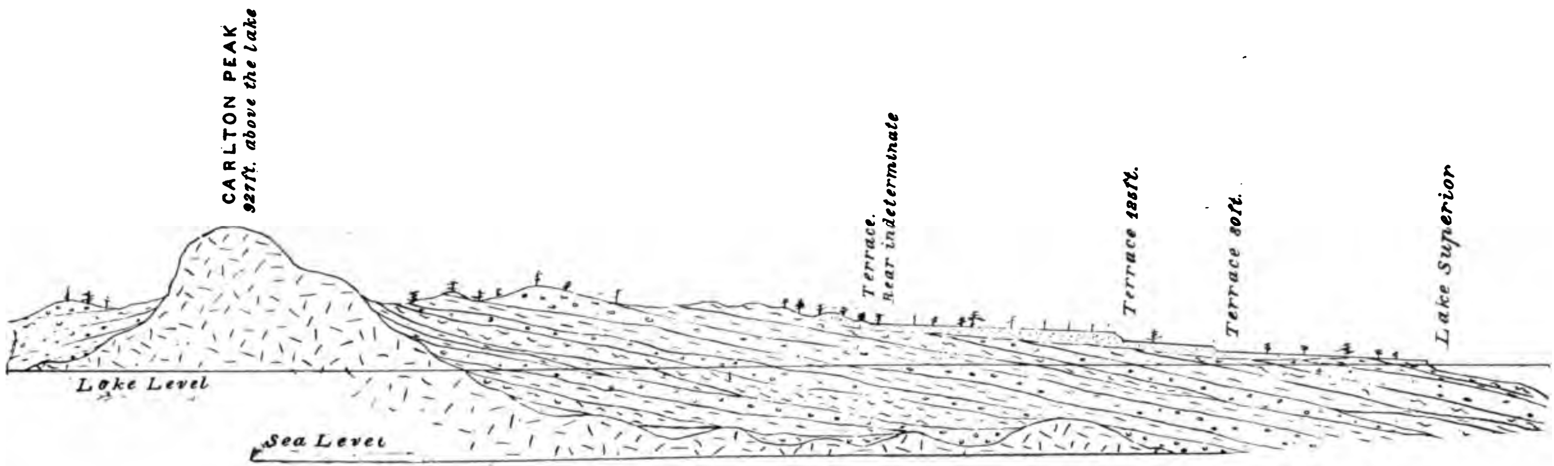


FIG. 1. Diagram of section on the east side of cove below Split-rock Point, showing anorthosyte ridge flanked by amygdaloidal feldspar-porphyry and amygdaloidal diabase-porphyryte, the latter holding a boulder of the anorthosyte imbedded in it. Scale 200 ft.=, 1 inch.



the gabbro, in which relatively fine gabbro surrounds the ends of the anorthite crystals as the base of any porphyry does the porphyritic crystals which lie imbedded in it."

This locality is a different one from that described by the writer as the cove immediately below Split-rock point, but the general conditions are the same. Notwithstanding the evidence of the included masses, Irving seems to have clearly regarded the anorthosyte as eruptive through the gabbro, which is probably the same geologically with the rock which the writer has recognized as a diabase-porphyryte. For he says in another place* "This anorthite-rock presents very interesting occurences, as described in a subsequent chapter. It appears both as masses cutting black gabbro, and as included angular masses in the same rock." This conclusion as to the eruptive character of the anorthosyte appears to the writer to be an error due to hasty or imperfect observation. Irving nowhere cites evidence of its eruptive character, beyond that it appears suddenly in the midst of his Keweenian flows, a statement which is quite true, but which is, of course, susceptible of a totally different explanation. There is positive, observable evidence of the Keweenian flows resting on the surface of the anorthosyte and being traversed by dykes of the same material as the flows. This fact taken together with the abundant inclusions of the anorthosyte fragments, which are not always angular blocks, but frequently rounded boulders, leaves no doubt whatever as to the relative age of the formations.

Winchell's views:—Prof. N. H. Winchell's views as to the occurences at Split-rock may be gathered from the following observations taken from his notes published in the ninth and tenth annual reports: "The west side of Split-rock river at its entrance to the lake is low, but the east side, or north-easterly, is high, and formed of a basaltic bluff or rock which appears on the immediate coast at a short distance east of the river. It there embraces a large block of a whitish-looking rock, which at a distance appears to be a granite, but which in reality is what has been described by Norwood as feldspar protruding through greenstone. This does stand up like a dyke, but is in reality older than the trap, and occurs generally further inland, forming hills several hundred feet high. This bluff rises sheer from the water 136 feet and has basaltic dark trap on each side of it, the rock itself being massive. On the

*Op. cit. p. 59.

east side of this high rock the trap shows included masses of the same rock, a fact which Norwood mentions, but yet speaks of the feldspar as a protuded mass of later date than the trap."*

Anorthosyte Confounded with the Keweenian Eruptives:—It will thus be seen that Winchell correctly interpreted the phenomena as indicating that the anorthosyte is an older formation than the eruptive with which it is associated. But he still regarded the anorthosyte as a member of the Cupriferous or Keweenian series. For, in the report for the following year he gives the following formulation of one of his conclusions: "The feldspar masses are of the same rock (geologically) as the Rice Point gabbro (?), and both are the result of copious and perhaps one of the earliest, igneous outflows of the Cupriferous. The more copious the igneous outflow, the coarser the resulting crystallization and the higher the hills formed, as well as the purer the labradorite material. The later outflows derived fragments from the "clinker fields" and from the knobs of feldspar already formed, as they passed along †

Thus none of the earlier observers, Norwood, Winchell or Irving, has differentiated the anorthosyte masses exposed at Split-rock from the general aggregation of volcanic flows which constitute the Keweenian series on the Minnesota coast.

Occurrences at Beaver Bay:—At the next high point on the shore to the east of Split-rock point the same conditions, as far as regards the inclusion of masses of anorthosyte in the dark lavas is repeated; but it is not till Beaver Bay is reached that the anorthosyte is again exposed in place. Here it may again be clearly observed in clean, wave-washed cliff sections to be the basement upon which the lavas were extravasated, and to have here also afforded numerous boulders and blocks which were caught up and enclosed in the lavas. All former notes as to the occurrence of anorthosyte at Beaver Bay are singularly deficient in geological information. Irving enters in some detail into an account of the geology of Beaver Bay, and publishes a special sketch map to show the distribution of the various kinds of rock, but he barely alludes to the anorthosyte.‡ Winchell's most important note is as follows: "Between Beaver Bay and the Great Palisades are numerous feldspar masses, in the coast series, and inland from the shore, a very short distance, is a range of low hills made up of feldspar with trap rock on the flanks."§

*Ninth Annual Report Geol. and Nat. Hist. Survey Minn., 1880, p. 30.
†Tenth Annual Report Geol. and Nat. Hist. Survey Minn., 1881, p. 114.
‡Copper-bearing Rocks, pp. 306, 307.
§Ninth Annual Report Geol. and Nat. Hist. Survey of Minn., 1880 p. 34.

PLATE III. Stratiform banded anorthosyte at Shingle Cove, near Beaver Bay, Minnesota coast, Lake Superior. The vertically jointed rock on the right hand is a dyke of diabase which cuts the anorthosyte.

At Beaver Bay there are four sèparate and distinct occurrences of the anorthosyte. The first of these is at the shingle cove at the extremity of the south-west headland of Beaver bay, and on the south side of the vertical cliff of red porphyry which here forms so striking a landmark. The anorthosyte occupies at this place an area of about 600 by 300 feet. The greater part of the mass, which rises to about 30 feet above the level of the lake, is the normal coarse whitish anorthosyte free from any special structural features. On the side facing the shingle cove, however, i. e., at the north-eastern extremity of the mass, a pronounced banded structure is apparent, resembling somewhat that described in the vicinity of Split-rock point. The stratiform appearance of the mass is well illustrated in Plate III. The dip is to the southeast. The stratiform structure is here due to the fact that there are certain sheet-like layers somewhat richer in pyroxene than the rest of the rock. The decomposition of the pyroxene has the effect of staining the layer so affected a yellowish or greenish rusty color, so that it presents a strong contrast with the unaffected portions of anorthosyte which lie between the layers. The decomposition of the pyroxene has not chemically affected the constituent feldspar of the rock except to a very limited extent, but it has the effect of mechanically disintegrating it so that it crumbles readily in the hand. Hence, as may be seen in the plate, the dark layers weather out as grooves or depressions. Under the microscope the feldspar in specimens from the dark bands is fresh, save for a few points where decomposition products appear. It is, however, much cracked and the yellowish decomposition products of the augite are distributed along the cracks. Norwithstanding the presence of these cracks these feldspars show no strain phenomena such as undulatory extinction, faulting, shearing, cataclastic structure, granulation, etc. The original allotriomorphic granular structure has not been disturbed, and it is highly improbable that banding is in any way associated with shearing action after the final solidification of the rock. It seems to the writer to be essentially due to some local chemical differentiation, associated with movement, in the thickly viscous magma prior to crystallization. This stratiform facies of the anorthosyte is at this place cut by a well defined dyke of olivine-diabase, which forms the jointed rock on the right in the illustration. The dyke is about 25 feet wide, is nearly vertical and has a strike corresponding with the general trend of the

coast. The anorthosyte is observable on both sides of the dyke. The latter has weathered out more easily than the anorthosyte, and its place is therefore marked by a depression, or negative dyke profile. In following this depression southward the olivine-diabase of the dyke is covered with great, loose blocks of the anorthosyte which have fallen from the wall on either side.

To the southward the anorthosyte gives way to a mass of hypersthene-diabase in which are enclosed many huge blocks of the former rock. Some of these blocks are 20 feet in diameter.

The second occurrence of the anorthosyte at Beaver bay is on the north-east side of the south headland of the bay where it forms two islets, as noted by Irving.

The third occurrence is on the north-west shore of the bay, extending from the base of the sand spit for over three-eighths of a mile north-eastward. The shore contour is serrated with alternating little rocky coves and points. In the bottom of nearly all the coves, as well as on several of the points, the anorthosyte may be seen in rounded *roches moutonnées* surfaces, with the diabase which predominates on the points either resting on it as a mantle, or eruptive through it in the form of dykes. The anorthosyte is practically continuous from the base of the sand spit for the distance above mentioned. The gracefully rounded forms of the old surface of the anorthosyte where it passes underneath the Keweenian flows is especially interesting and is well illustrated in Plate IV.

Another contact showing the same relationship is illustrated in Plate V. The hummocky and *roches moutonnées* aspect of the old anorthosyte surface is entirely analogous to the phénomena which the writer has elsewhere* described as prevalent at the contact of the Keweenian (Nipigion) and the Archæan in other parts of the lake Superior region.

The anorthosyte is traversed here not only by dykes of diabase but also by the common, red, acid eruptive of the country (quartz porphyry and granophyre) which, in the form of irregular dykes, intersects the older dykes of diabase. The diabase which lies on the anorthosyte holds many large blocks and boulders of the latter of the same character as those previously described. It is strongly amydaloidal in places.

*Note on the pre-palæozoic surface of the Archæan Terranes of Canada, Bull. Geol. Soc. Am. Vol. I, pp. 163-174.

The fourth occurrence of the anorthosyte rock is at the first falls of Beaver river and is described by Irving in the following paragraph: "At several points along Beaver river this black gabbro carries large masses of anorthite-rock [anorthosyte] similar to that described as occurring further up the coast. The boulder like character of the anorthite-rock, though often pronounced is not always so plain and in some places it looks more like a dependency of the prevailing black gabbro.* A careful inspection of the occurrence by the writer enables him to state that there is no reasonable doubt whatever, of the foreign and included character of the anorthorsyte boulders.

Shore below Beaver Bay :—The next locality down the coast where the anorthosyte appears is at a point about a mile and a half below the north east headland of Beaver Bay and directly opposite a small island which lies about a quarter of a mile off shore. Here the anorthosyte emerges from beneath the sheeted trap rocks, and has an exposure of over one hundred yards in the form of bold, yellowish-white domes. It also occupies the island above mentioned which is about one-eighth of a mile long. The island is traversed by two vertical dykes having a strike transverse to the general trend of the shore. One of these dykes is 200 feet wide and is of the character of a diabase or gabbro, very dark in color, coarse in texture and rich in iron ore. The second dyke is quite small and may be simply an apophysis of the larger one. The contact of the dykes with the anorthosyte which occupies the mass of the island is sharply observable as a vertical plane with the intrusive rock somewhat finer grained near the dyke wall than at points near the middle. A quarter of a mile further down the shore the anorthosyte again appears in an exposure several hundred yards in extent and is here also clearly intersected by dykes of the dark diabase.

Half a mile further on at a point on the shore about three-quarters of a mile beyond the east end of the island above mentioned, the anorthosyte is again exposed; and here, just as at Beaver Bay, the domed surface of the old pre-Keweenian terrane is seen to be capped with a sheet of amygdaloidal diabase which adjusts itself to the curvature like a mantle.

Irving's observations on these exposures are summarized in the following note: "At several points in this vicinity the black rock was observed to include masses of coarse anorthite-

*Copper-bearing Rocks, p. 306.

rock. The latter did not appear to occur here in boulder-like masses, but rather in irregular outlined areas. At one point on the shore of Sec. 6, directly west of the island above referred to, *the white anorthite-rock rises like a dome in the black gabbro, which is seen above it and on both sides of it.** The southern point of the island is formed of anorthite-rock; and due north from this point, on the mainland, is another area of white rock apparently trending north and south." It is difficult to understand why Irving failed to appreciate the fact that the anorthosyte areas represent the eroded surface of a pre-Keweenian terrane.

Baptism River: The next locality where this interesting formation appears is on the Baptism river, about half a mile up stream from its mouth. In the vicinity of the foot-bridge, which here spans the rocky gorge of the stream, the anorthosyte is observable both in large masses not fully exposed, and in the form of boulders several feet in diameter imbedded in vesicular and amygdaloidal lava.

On the Slope of Saw-teeth:—Farther along the coast about two miles and a half below the mouth of Baptism river, the anorthosyte again crops out on the summit of a forest-clad hill about half a mile inland from the lake, and 300 feet above the level of its surface. The exposure has an extent of 100 by 25 feet and its relations to the flanking eruptives are not revealed.

Carlton Peak:—The next occurrence of the anorthosyte is at Carlton peak, a little below the Temperance river. This exposure is the most extensive and probably the most important of any on the coast. This fact that the summit of the peak was composed of this rock was first announced by Norwood† who stated that it was "composed entirely of feldspar rock" but imagined that it was a huge dyke. Irving makes the following statement regarding the occurrence: "The high bluff known as Carlton's peak, near Temperance river, shows at its summit numerous large angular fragments of anorthite-rock, such as has already been described in connection with the Beaver Bay group. None was seen that could certainly be regarded as in place; nevertheless the mountain is without much doubt, composed of this rock, and I should regard the rock as having antedated the Temperance group flows rather than as a cutting mass." It is quite apparent from this statement that Irving himself did not visit the summit of Carlton peak, and must have based his

*The italics are the writer's.

†Report of the Geol. Survey of Wisconsin, Iowa and Minnesota by D. D. Owen p. 380.

statement, as to the occurrence there, upon the imperfect observations of others. The writer ascended the peak, and not only confirmed Norwood's statement that the summit is composed of anorthosyte, but also found that the whole upper half of the mountain is made up of the same material. The exposure is an exceedingly bold and striking one. The peak is 927 feet high above the lake and about a mile and a half distant from the shore. It rises in the form of a great dome and is a very conspicuous land-mark; the domed aspect being, however, confined to the upper part of the mountain. The mountain is flanked on all sides by the sheeted lavas of the Keweenian and these, by their gentle dip lake-ward, constitute an easy grade to the declivity of the dome, nearly half way to the summit. This gentle slope is heavily timbered and in part terraced, but has been burnt in places; while the upper half of the mountain is practically a continuous bare surface of anorthosyte, presenting to a remarkable degree of perfection the *roches moutounées* curves down to where it plunges beneath the mantle of lavas which flank the base. The mass has none of the characters of a dyke or intrusive boss as Norwood supposed. The relations which obtain are illustrated in the accompanying diagrammatic section Fig. 2.* The area of anorthosyte exposed at Carlton peak is probably more than half a mile square. Beyond Carlton peak no other exposures of anorthosyte have been observed down the coast, and none are known in Canadian territory in the region around the lake.

GEOLOGICAL RELATIONS OF THE ANORTHOSYTE.

Pre-Keweenian Age:—In the foregoing pages sufficient evidence has been set forth to demonstrate the pre-Keweenian age of the anorthosyte. This evidence is four-fold. (1) The anorthosyte is traversed by dykes of the Keweenian eruptives both acid and basic. (2) The Keweenian lavas hold imbedded in them innumerable boulders and blocks of anorthosyte evidently detached from a pre-existing terrane. (3) The anorthosyte forms the surface upon which the Keweenian lavas now rest, and upon which they were originally extravasated. (4) The anorthosyte affords both by its petrographical character and by the nature of its surface the most satisfactory evidence of profound erosion prior to the extravasation of the Keweenian eruptives.

Domed and Hummocky Character of the Pre-Keweenian Surface:—Not only does the surface of the anorthosyte demonstrate the erosion of that formation in pre-Keweenian time, but it shows

*Facing page 12.

that the Keweenian lavas have only to be stripped from its surface, by the ordinary forces of denudation, as has been done in several instances cited, in order to afford us the typical domed, hummocky, and *roches moutonnees* surface which is usually ascribed to glacial action. This type of surface prevails over the greater part of the Archæan terranes of Canada and passes in this peculiar condition under the base of the palæozoic column wherever the contact has been observed. The writer has in a former paper inferred from this fact that the hummocky character of the Archæan terranes of Canada is not, as is commonly supposed, ascribable wholly to glacial action in Pleistocene time, but that it is essentially pre-palæozoic in its origin, being only modified by Pleistocene erosion.* The beautifully clear evidence here recorded and illustrated (Plate IV) as to the domed and *roches moutonnees* surface of the pre-Keweenian rocks of the Minnesota coast where they pass under the Keweenian lavas, is in harmony with the descriptions and conclusions given in the paper referred to; and demonstrates that in this regard the anorthosytes have one pronounced feature in common with the Archæan of other parts of the lake Superior region.

Interval of erosion:—The character of the anorthosyte as set forth in the petrographical notes is such as to warrant the assumption that it is a plutonic formation, and that it solidified in the form in which we now see it under deep seated conditions; and that therefore the amount of erosion necessary to reveal it at the surface must have been great. The interval in which the work of erosion was effected, was probably the same pre-palaeozoic interval as that which effected the reduction of the Archæan to the great hummocky plane which occupies so large a part of the North American continent, and which reveals at the surface the great areas of Archæan granites.

Absence of the Animikie:—The recognition of a pre-Keweenian terrane on the Minnesota coast involves certain consequences of geological importance. One of these is that the formations of the Animikie so largely developed in the vicinity of Thunder bay, and there underlying the Keweenian, are here wanting. Former writers have assumed the existence, beneath the Keweenian, of the Animikie rocks along the entire coast. But the repeated outcrops of the anorthosyte at the base of the Keweenian shows that for the middle third of the Minnesota coast, at least, the Animikie, is wanting. The relations thus become

*Pre-Palæozoic Surface of the Archæan Terranes of Canada. Bull. Geol. Soc. Am., *Vol. 1, pp. 163-174.*

entirely analogous to those which obtain on the Canadian portion of the lake Superior coast beyond Thunder bay where the Animikie is wanting and the Keweenian (Nipigon) rests directly upon the hummocky surface of the Archæan.

Shallowness of the Keweenian: — Another important consequence, resulting from a recognition of the true character of the anorthosytes, is a correction of Irving's estimate of the thickness of the Keweenian. In his account of the stratigraphy of the Minnesota coast, Irving places the thickness of the Keweenian series at 20,000 feet, stating that, in all probability, it may reach 22,000 or 24,000 feet.* Disregarding the first group, the St. Louis gabbros, for the thickness of which he admits he can give no good figures, he places the thickness of the remainder of the Keweenian at 17,000 feet. At Split-rock he places the thickness at 16,000 feet, and at Temperance river the maximum of 17,000 is reached. There is something sadly astray with these estimates, and with the stratigraphy upon which they are based. According to Irving the Keweenian series on the Minnesota coast is thickest along its middle third. It is along this part of the coast that the underlying basement, upon which the Keweenian rests, crops out sufficiently abundantly to demonstrate that the series is comparatively thin, ranging from zero, locally, up to a few hundred feet. The Keweenian on this coast is by no means the excessively thick series that it has been represented to be. In the opinion of the writer, its maximum thickness is not more than one-tenth of the value at which Irving placed it. All estimates based upon the dip of the lava sheets are fallacious, unless it is clearly recognized that a large part of the dip is the original slope of the surface over which the lavas flowed; and that there is a constant and scarcely avoidable danger of piling up contemporaneous flows, one on top of another, by an undue extension of imaginary stratigraphic planes. In this way figures are obtained for the thickness as enormous as they are absurd. The stratigraphy of volcanic flows and instrusive sheets, traversed by many dykes, is not so simple a problem as Irving seems to have regarded it, and his analysis of that stratigraphy, his subdivision of the Keweenian into groups, and his estimates of the thickness of the various portions of the series are of little value; a statement which it is as painful to make as it is necessary in the interests of sound geology.

*Copper-bearing Rocks, p. 266.

Correlation and name of the formation:—Petrographically, the anorthosytes of the Minnesota coast are closely allied to certain great masses or areas of plagioclase rocks which prevail in the Province of Quebec, and which are known also in the Adirondacks and in New Jersey. Adams, who has given many years of study to the Quebec occurrences, has shown that they are irruptive masses breaking through the ordinary gneisses of the Archæan.* It would appear, however, that they long antedate the advent of the palæozoic, that they were plutonic intrusives in the Archæan prior to the great interval of erosion which separated the Archæan and Palæozoic, and that their appearance at the present surface of that region is due to prepalæozoic denudation. On the lake Superior coast the relation of the anorthosytes to the Archæan rocks is not revealed, but it seems highly probable that they are, here also, pre-palæozoic, and were also plutonic intrusives in the Archæan and exposed at the pre palæozoic surface by the same erosion as that which denuded the anorthosyte areas of Quebec. Moreover the writer has elsewhere† noted the occurrence of plagioclase rocks at Bad Vermilion lake, under the name of saussurite gabbro, which are intrusive in part of the Archæan. This saussurite gabbro is for the most part composed wholly of basic plagioclase, and differs petrographically from the Minnesota anorthosytes chiefly in the decomposition of the feldspar into the saussurite aggregate. Dykes of very coarse plagioclase rock (saussuritic) have also been observed by the writer traversing the Archæan on the international boundary at Ottertrack lake, about forty miles north of Carlton peak.

Fully aware of the danger of establishing geological correlations on a petrographical basis, the writer is nevertheless disposed to accept the suggestion which these petrographical analogies offer, and to enunciate the hypothesis that the anorthosytes of the Minnesota coast are the geological equivalents of the anorthosytes of Quebec, i. e., that they are plutonic irruptives invading the Archæan, and yet long anterior to the Taconic or basal system of the palaeozoic rocks. For rocks of such a relationship the term Norian will doubless be eventually retained in geological nomenclature. Were the correlation here suggested scientifically demonstrable the name Norian would be a sufficient designation for the geological formation composed of these anorthosytes. Since,

*Geological Survey of Canada. Summary Reports for 1887 and 1888.

†Geol. of Rainy Lake Region. Geol. Survey of Canada. Annual Report 1888, pp. 56-57

ıowever, the correlation is merely an hypothesis, to serve as a ›asis for future discussions, a local name for the formation s highly desirable. The writer, therefore suggests the ıame "Carltonian," from Carlton peak, where the formation s most extensively exposed, as the geological designation of he formation; and he tentatively correlates the Carltonian ›f lake Superior with the Norian of the Province of Quebec.

II.

THE LACCOLITIC SILLS OF THE NORTHWEST COAST OF LAKE SUPERIOR.

INTRODUCTION.

General Note—Among the salient geological features of the northwest coast of lake Superior, the most prominent are probably the remarkable sheets of "trap" which are constantly associated with the Animikie and Nipigon groups of sedimentary rocks, between Pigeon river and the Slate islands. It is to the presence of these trap sheets that the bold and picturesque topography of Thunder cape, McKay's mountain, Pie island, Nipigon bay, and the many sheer-walled mesas and tilted blocks of the region is due.

These trap sheets are usually nearly horizontal, and are of great extent. They occur in two ways: (1) In the form of thick sheets, usually from 50 to 200 feet in thickness, (occasionally 300 or even 400 feet) at the summit of the local stratigraphic column, resting on the little disturbed shales and sandstones, and constituting the surface of the tableland or mesa. In geological descriptions these thick sheets have been referred to as "trap caps." (2) As thin sheets, usually from 4 to 20 feet in thickness, intercalated with the shales and sandstones at a much lower level in the local stratigraphic column.

These trap sheets are prevalingly diabase, passing in places into gabbro, and have been regarded by all previous writers on the geology of the region as wholly or in part volcanic flows. The lower and thinner sheets have been regarded as contemporaneous with the sedimentary rocks with which they are intercalated, and the capping sheet has been referred to very commonly as the "crowning overflow," and by one writer has been designated the "gabbro flood." These sheets are very characteristic associates of the Animike group, and from the descriptions which have been given the notion is current, both

in literature and among geologists who have had occasion to become familiar with lake Superior geology, that the Animikie group is, like the Keweenian, partly volcanic in its composition.

Earlier descriptions—This idea was first enunciated by Logan, who in his description of the rocks of the north shore of lake Superior *refers thus to the formations now known as the Animikie group: "Bluish slates or shales interstratified with trap, * * * * *. Trap bands conformable with the stratification are interstratified in several parts of the vertical amount, but they occur in greatest thickness towards the bottom not far from the cherty beds, and at the summit overlying the whole formation. * * * In all cases it presents a very striking sub-columnar structure at right angles to the plane of the stratification, and the crowning overflow gives a peculiar aspect to the whole region occupied by the formation to which it belongs."

Practically the same language was again used by Logan in his account of the geology of Canada published in 1863.

Bell adopted the same view, that these trap sheets are surface volcanic flows, but recognized that they are, in part at least, later in age than the bulk of the Nipigon rocks, from the fact that the sheets in places cap the Nipigon strata†.

Irving objects to the idea of any single "crowning overflow," but clearly regarded the greater part of the trap sheets as contemporaneous volcanic sheets, as may be gathered from the following quotations:

"So far, then, as I have been able to learn from original observations, and by reading in the light of the observations the accounts of others, the Animikie rocks of the Pigeon river-Thunder bay region consist of a great series, probably upwards of 10,000 feet in thickness, of quartzites, which are often arenaceous, quartz slates, argillaceous or clay slates, magnetitic quartzites and sand-stones, thin limestone beds, and beds of a cherty and jaspery material. With these are associated in great volume, and in both imbedded and intersecting masses, several types of coarse gabbro and fine grained diabase, all of the types being well known in the Keweenian series.‡ Again referring to Bell's stratigraphical scheme for the Animikie, Irving says: "Then again, the great

*Report of Progress, Geol. Survey of Canada 1846-7 p. 13.
†Geol. Survey of Canada Report of Progress 1866-69.
‡Copper-bearing Rocks, p. 379.

volume of included beds of gabbro and diabase is almost entirely ignored. In the third division of his scheme it is said that trap beds are associated with these rocks along the north shore of Thunder bay, at the Thunder bay mine, and in the township of McIntyre, and yet the whole volume of this division is placed at only 450 feet. But as seen, all the way from Wauswaugoning bay, on the Minnesota coast, to the south side of the Kaministiquia valley, and again in the Pigeon river country of Minnesota, these included beds must aggregate over a thousand feet (?) *while they may be much more than this (? ?).† This important omission is probably to be explained by Bell's having regarded all of these beds as part of the so-called "crowning overflow" which is supposed to have taken place after the accumulation and removal of thousands of feet of the newer Keweenian or copper-bearing strata.

"The only evidence of any such general overflow consists in the similarity of the crystalline rocks found capping the hills in different parts of the region. Not only is it much more in accordance with the geology of the lake Superior region to suppose these occurrences to represent many different flows, but there is distinct evidence that they do so in many cases. This evidence consists in part in actual visible interstratification with the slates in some places of great beds of olivinitic gabbro identical both macroscopically and miscroscopically with the rock capping Thunder cape. Another evidence is the very great irregularity of level of this supposed flow must occupy, the hight at which it is found varying back and forth through distances of several hundred feet. Yet stronger evidence is found in the general structural character of the region, by virtue of which each heavy, enduring, crystalline rock layer constitutes a ridge with a long front slope and a preciptious back slope."‡

Selwyn, in 1884, adopted the same prevalent views as to the partial volcanic composition of the Animikie group. Writing in that year, he says: "Between Thunder bay and the east end of Nipigon the three series (Animikie, Nipigon and Keweenian) follow each other without apparent unconformity and dip at generally low angles towards the lake. Up to the summit of the Nipigon series there are many larger interstratified beds of columnar diabase, then follows the Keweenian

*The queries are the writer's.
*The queries are the writer's.
*Op. Cit. pp. 381—382.

series, consisting, etc. * * * The absence of palæontological evidence of age may be, perhaps, in a great measure, accounted for by the great and repeated manifestation of volcanic activity over the whole region during the accumulation of the sediments, producing conditions highly unfavorable for the existence of animal life."* From various references scattered through the writings of Murray, McFarlane, Hunt and McKellar it is clear that all of these observers regarded the sheets associated with the Animikie slates, sandstone, etc., as contemporaneous volcanic flows.

The late Prof. Alex. Winchell in speaking of the trap sheets which cap the Animikie slates in the vicinity of the international boundary, used the following words: "The great gabbro flood. I agree fully with American geologists in assigning a primitive molten condition to the sheet of gabbro which covers so many hundreds of square miles in the northwest. But its wide extent considered as a molten flood, is a fact which excites amazement. * * * * * a total of thirty-nine townships or 1,152 miles, once in the history of the state covered by a glowing flood of molten rock.†

The views of N. H. and H. V. Winchell are expressed recently in the following terms: "The Taconic (Animikie) in northeastern Minnesota, therefore, with some periods of quiet, was deposited in the midst of violent volcanic disturbances and oceanic transportation."‡

The best account of the Animikie group that has yet appeared is that given by E. D. Ingall in his report on Mines and Mining on Lake Superior.‖

To Mr. Ingall belongs the credit of taking the first steps in rectifying current misconceptions regarding the geological relations of the trap sheets associated with the Animikie strata In several specific instances he shows in this paper that the trap sheets are not contemporaneous flows, but are true intrusive sheets. But notwithstanding the clearness of the truth which he discovered, he seems to have been so influenced by the weight of authority of previous writers that his discovery remained only a partial one, and its full significance was not realized; for he speaks in his introduction of "Sedimentary and volcanic rocks of the Animikie,"§ and a little further on he says,

*Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, 1884, pp 21, 22.

† Geological and Natural history survey of Minnesota, sixteenth annual report. p.361.

‡ Iron ores of Minnesota, Bull. No. VI, Geol. and Nat. Hist. Survey of Minnesota, 1891, p. 114.

‖Geol. Survey of Canada, annual report 1888, part H.

§Op cit. p.8

"the rocks comprising this silver bearing formation (Animikie) consist of basic traps, black and gray argillites, cherts and jaspers, with some ferruginous dolomytes etc."* The evidence of the intrusive character of some of the sheets, which Mr. Ingall adduces, will be reverted to in the sequel.

It thus appears from a review of these references to the writings of most of the geologists who have had occasion to to become personally familiar with the Animikie group that the uniform teaching has been that the series is partially composed of volcanic rocks. Most observers have regarded all of the igneous rocks associated with the Animikie series as volcanic surface flows. Two observers only, Irving and Ingall, have recognized the intrusive character of some of the sheets; and of these Ingall observed so many cases, that it is a matter of surprise that he did not attempt to generalize somewhat from his evidence.

Dissent from former views—This doctrine of the volcanic character of the igneous rocks associated with the Animikie is one which the writer is disposed to deny. The writer believes that he has a field knowledge of the Animikie rocks not less extensive than that of any other geologist who has heretofore written upon then. He knows them from Gunflint lake to the most easterly islands of Nipigon bay. He has examined their entire exposure, in all its magnificence, along the coast of lake Superior from Grand Portage bay to its most easterly occurrence on the main shore. Traveling on foot, he has examined all the sections which are revealed on the line of the Canadian Pacific railway, both east and west of Port Arthur. He has followed the line of contact of the Animikie against the Archæan probably more closely than any other geologist who has put his observations on record. He has visited and descended most of the important silver mines that have been in operation during the last six years. He has examined the well known exposures on the wagon and canoe route from Port Arthur westward by way of Rabbit mountain, the Palisades, Silver Mountain, Whitefish and Arrow lakes, and the lakes of the international boundary. He has also traversed the Kaministiquia river in canoe, and has made many minor excursions throughout the district occupied by the Animikie rocks.†

* Id p. 23.

†The various examinations which the writer has made from time to time of the Animikie rocks have been incidental to, or apart from, his major work in the lake Superior region; and his knowledge of the series has, therefore, been gathered piece-meal. and has led to no systematic account of its geological features. The last necessary and important information was obtained while examining the coast of the lake in the summer of 1891, under the auspices of the Geological and Natural History Survey of *Minnesota*. The earlier notes were obtained while conducting geoloical gwork for the *Geological Survey of Canada*.

With these exceptionally favorable opportunities for observation, with a strong interest in the ingeous rocks of the region, and having always had in mind the question which is to be dealt with in this paper, the writer has failed, after a prolonged and critical inquiry, to find anywhere in the Animikie group any trace whatever of volcanic rocks.

Views here advanced—In view of this somewhat extensive familiarity with the Animikie formations, the writer feels warranted, from his failure to find volcanic rocks, in laying down the proposition, that *there are no contemporaneous volcanic rocks in the Animike group.*

He dissents, moreover, from the view which has been entertained by some writers, Bell, particularly, that the "trap cap" or so called "crowning overflow" which is found reposing on the Animikie, is a volcanic extravasation, though not contemporaneous, since the same sheet has been observed to cap also the Nipigon series; and he maintains that *none of the trap sheets associated with the Animikie, whether of the nature of "caps" or intercalated sheets, is a volcanic flow.* He further maintains that *these trap sheets are all intrusive in their origin, and are of the nature of laccolitic sills.*

The last two of these propositions the writer believes to be susceptible of demonstration. The first on account of its negative character cannot be so surely established. But since these trap sheets are the only rocks which have ever been supposed to be volcanic, if the last two propositions can be maintained, geologists cannot go on assuming and teaching as they have done in the past, that the Animikie group is partially composed of volcanic rocks. For nowhere in geological literature is there any good evidence recorded of the existence of contemporaneous volcanic rocks, and in none of the hundreds of unrivaled sections, which the cliffs and mesa scarps of the Animikie present, has any igneous rock, intercalated with the sedimentary strata, been found, other than these trap sheets. An attempt will, therefore, be made to show that these trap sheets are intrusive sills; but in doing this no effort will be made to treat the subject exhaustively. The petrographical characters of the rocks will not be entered into in detail, although they present a very inviting field for investigation from certain points of view. Neither will any effort be made to array great numbers of specific, detailed observations of field relations; for that would be wearisome, and is unnecessary till such time as the views here presented be challenged and their truth

doubted. The general statements which the writer will make, together with the occasional specific references, are sufficient to establish his thesis.

PETROGRAPHICAL CHARACTER OF THE TRAP SHEETS.

The so-called "trap" sheets associated with the Animikie group embrace two distinct types of rocks: (1) Diabase (2) Granophyric quartz-porphyry. The first of these is by far the most abundant. It very frequently has olivine present as an important constituent, and would then be termed an olivine-diabase. In structure it passes locally into a coarse gabbro or olivine-gabbro on the one hand, and on the other into a fine grained porphyryte. The prevailing color is a pepper and salt gray, the fresher the rock the lighter being the color. Where the pyproxene is found to have been altered to hornblende, and other changes have taken place, the rock is usually darker in color. Opaque iron ores are generally never absent from the slides of these rocks. The ophitic or diabase structure is very pronounced and is much more prevalent than the allotriomorphic granular structure, notwithstanding the fact that Irving and others commonly refer to the rock as gabbro. An abundant crop of phenocrysts seems to have been developed in some few localities in the coarser varieties of the rock, and the formation then is strongly porphyritic, as on the shore west of Caldwell point. Another feature of interest but also quite local in its occurrence is the presence of irregular patches or blotches or blebs of quartz in the mass of the rock. These may be seen to advantage on the Canadian Pacific railway about five or six miles east of Port Arthur. Locally, also, the constituent feldspar of the diabase assumes a brick red color and the rock in consequence has a reddish color. This is common in those portions of the formation which are charged with inclusions of quartzyte fragments from the Animikie series, but is also observable when such inclusions are not to be found.

This assumption locally of a reddish color renders it sometimes difficult to distinguish the diabase, without very critical examination, from the second petrographical type affected by these sheets, viz., the quartz-porphyry, which is also of a brick red color, and frequently has a ferro-magnesian silicate as a normal constituent. This red granophyric porphyry is, however, not of general distribution like the diabase, but is found chiefly on the islands southwest of Pie island, and on points opposite Victoria island and thence southwestward on the mainland. In *some of its* phases it resembles some of the various "red-rock"

formations on the Minnesota coast, which have by former investigators been classed as Keweenian flows. Most of it seems to be indistinguishable in its essential characters from the "red rock" of Pigeon point which has been so ably investigated by Prof. Bayley, who indentifies it as soda granite and quartz-keratophyre, and advances a remarkable explanation of its mode of development, which the writer, after a careful examination of the conditions revealed on Pigion point, believes to be correct.* The area occupied by these sheets of red rock within the Animikie province is, however, small, and some portions of them vary considerably from the true quartz-porphyry facies, and appear from their field relations to be intermediate graduations between an acid quartz-porphyry and the diabase, as if by the mixture of acid and basic magmas. To establish such a supposition would, however, require a large amount of thorough petrographical study. Prof. Bayley's careful work at Pigeon point sets the example of the true method of attacking these highly interesting problems in petrogeny. There is no place for their discussion in this paper.

Constancy of character—The sheets of diabase are, with the local exceptions above mentioned, remarkably constant in their petrographical characters over wide areas of country. They are, for example, invariably holocrystalline and no glassy portions have anywhere been detected in them. They are never amygdaloidal, a fact which has been frequently noted by earlier writers. In this respect the trap sheets present a very marked contrast to the volcanic lavas of the Keweenian, which are generally amygdaloidal. This total absence of amygdaloidal and vesicular structure is a very strong argument in itself against these sheets being surface flows.† The sheets also have very constantly a columnar or sub-columnar structure transverse to the plane of their extension. This columnar structure moreover extends through the entire sheet, from the lower surface to the upper. This, again, is in contrast with the columnar structure observable in thick surface flows. In these cases the columns are also prevalingly at right angles to the cooling surfaces, but they do not, so far as the observations of the writer serve him, extend completely through from surface to surface. In their

*Origin of the Soda Granite and Quartz-Keratophyre of Pigeon point, by W. S. Bayley Am. Jour. of Sci., Vol. XXXIX April, 1890.

†In one instance the writer has observed an amygdaloidal rock in the Animikie province, but this has no connection with the trap sheets and is probably an out-lying remnant of the Keweenian. cf. Note on the occurrence of native copper in the Animikie rocks of Thunder bay. The American Geologist, March, 1890.

columnar structure these trap sheets are entirely analogous to the numerous dykes of the region, in which the columnar structure is pronounced from wall to wall of the dyke.

Petrographical differentiation—While thus emphasizing the constancy of the petrographical character of these sheets, it is not the intention to assert that there is no petrographical differentiation within the sheet itself. There is, indeed, a very pronounced and evident variation in the character of the rock composing each sheet. But this variation obeys a definite law, and is constant for every sheet, so that the variation itself becomes an invariable character, wherever the full thickness of the sheets may be observed. This petrographical variation is strictly analogous in its physical aspects to the differentiation which the writer has described as characteristic of the dykes which traverse the Archæan terranes in the Rainy lake region.* Whether there is also a corresponding chemical variation as in the case of the dykes, has not yet been investigated. Whereever the contact of the trap sheets with the Animikie slates has been observed, whether at the lower or the upper surface of the sheets, the diabase at the immediate contact has been found to be a dense compact rock, either microcrystalline or quite aphanitic with occasional minute phenocrysts of plagioclase scattered through it. The texture of the rock becomes coarser rapidly as the distance from the contact is increased, and if the sheet is thick the rock is usually quite coarse at the distance of a few yards from the contact. In the structure, as exhibited in a number of representative slides from different localities, the rock varies from that of a dense, very fine grained diabase-porhyryte into that of a fine grained diabase, the ophitic structure being pronounced, and then to that of a coarse diabase with a tendency in places to assume a granular structure.

Analogous, though somewhat different, variations in texture and structure, also obtain for the sheets of red granophyric quartz-porphyry, at least so far as their lower contact is concerned, as may be clearly observed on Victoria island. These variations in texture and structure, particularly in the diabase, are well known to be characteristic of the contact phenomena of intrusive masses; and taken together with the strong similarity in the field aspect of the sheets to the dykes of the region, the presumption in favor of regarding them as horizontal dykes or intrusive sills becomes very strong.

*Petrographical Differentiation of Certain Dykes of the Rainy Lake Region. The *American Geologist*, March, 1891.

SOME BROAD FEATURES OF THE TRAP SHEETS.

Their Simplicity—Another argument in favor of the intrusive character of the sheets is their simple and uniform character regarded as geological masses. In this they again resemble the great dykes that traverse the region. In the case of surface flows, whether from volcanic craters or from fissure outwellings, it is an exceedingly abnormal condition of affairs to find the extravasation take the form of a *single* sheet, occupying hundreds of square miles and of practically uniform thickness. Yet this is precisely the character of the sheets under consideration. Their simple individuality, their regularity, the total absence of over-lappings of one sheet on another, are features which are sufficient to negative the supposition that they are surface flows. The unity and persistence of the sheets over wide areas is remarkable. The Animikie strata and these associated trap sheets have together been dislocated by a great system of faults; and the orographic blocks so formed have been very frequently tilted, so as to present a long gentle slope to the south-east, and a steep scarp to the northwest. The angle of tilt has been small ranging usually from 0° to 5°, but is sometimes higher; and portions of the region afford a remarkable illustration of this tilted structure, and of a topography conditioned by it. The many long, narrow lakes which occupy the Animikie province in the vicinity of the international boundary clearly lie in fault lines, between a steep scarp on one side, and a more or less gentle slope on the other. The non-recognition of this prevalent tilted structure has been the origin of much confusion in the descriptions of the Animikie group; and very excessive estimates of the thickness of the series have been made both by Irving* and by Ingall.†

In the opinion of the writer one fifth of these estimates is much nearer the true thickness than the figures given by these geologists. The recognition of the tilted structure renders the correlation of discrete portions of a single sheet a matter of no great difficulty to a stratigraphic geologist. Such a correlation, based upon correct ideas of the structure, shows clearly that the trap sheets are few in number, and single sheets may be traced in geological continuity for many hundreds of square miles. This persistence of single sheets, more noticeable in the thick "trap caps" than in the thinner intercalated sheets, is even

*10,000 feet. Copper-bearing Rocks p. 380.
†12,000 feet. Report on Mines and Mining in Lake Superior p. 26.

more evident on the lake front, where tilting is less pronounced and the sheets may be traced in actual, as well as geological continuity, over equally great areas with practically uniform thickness. In other cases, where the level-topped mesas are dissected by erosion and separated into several topographical masses by valleys of greater or less width, there can be no reasonable doubt of the original continuity of the separate caps of the now isolated hills, since they occupy the same levels, overlie the same rocks, have the same general thickness, and the same peculiarities of petrographical detail both macroscopic and microscopic. This persistence and the practical uniformity of level (prior to tilting), together with the fairly uniform thickness of the sheets constitute a combination of features not affected by surface flows.

Absence of Pyroclastic Rocks—The sheets are nowhere associated with pyroclastic rocks such as would suggest their extravasion at the surface. There is no ash, or tuff, or coarse agglomerate. Neither is there any trace of breccia or recemented lava fragments of any kind, such as are commonly developed in the progress of a surface flow of lava.

Absence of flow structure—There is, moreover, a complete absence of flow structure such as is so abundant in the lavas of the Keweenian. This is true of the surface of the sheets as well as of their internal parts. The surface of the Keweenian lavas is very frequently characterized by the presence of wrinkles and of other manifestations of what is known as "ropy structure." These features are never found on the surfaces of the trap sheets, even where these are freshly exposed by the recent removal of the over-lying slates.

The enclosing rocks—Another feature which does not accord with the supposed surface character of these sheets is, that the sedimentary strata below the sheet are usually, so far as observation is possible, the same as the strata which immediately overlie it, Of course, as regards the thick trap caps of the region, there are generally not now any strata reposing upon them, and it is, therefore, impossible to say what the nature of the overlying beds originally was. But as regards the intercalated sheets, the statement is true that there is no essential difference in the character of the enclosing rocks above and below the sheet; and on the surface of the thick trap sheet, which extends inland from the town of Port Arthur and skirts the north shore of Thunder bay, and which is, for the most part a cap sheet, there are numerous remnants of the overlying

Animikie slates still adhering to the trap (see Plate VI, *Frontispiece)* which are the same rock essentially as the slates which underlie the sheet.

Intersection of strata by the sheets—Owing to the little disturbed condition of the Animikie strata, and to the fact that the sheets had their origin prior to the disturbance, the sheets appear commonly to follow in each case a single geological horizon. To this apparent rule, however, there are very numerous exceptions, and generally if the sheets are followed in detail their surfaces are found *not* to be strictly parallel to the bedding planes of the Animikie strata, but to intersect them to a greater or less extent. Generally the intersection is of a minor character. Sometimes, however, it amounts to an important passage from one geological horizon to a very different one. Many of these intersections of the Animikie strata by these trap sheets have been observed and recorded by Ingall.*

One or two cases have been noted by Irving, † and others have been observed by the writer. One of these intersections is well illustrated by Ingall in the lower figure of the plate facing page 24 in the report above referred to. Although this is entitled an illustration of a "Trap *flow* on Argillytes;" it is, undoubtedly, an intrusive contact, as Mr. Ingall himself is disposed to admit. In addition to the observations of Ingall and Irving a few other cases noted by the writer on the coast may here be given.

On the face of the high bluff which rises on the south side of Sturgeon bay, the trap cap may be seen not only to abruptly change its thickness and to pass up over the edges of the slates, but also to send a long tongue-like prolongation within the latter apparently parallel to the bedding. On the south side of Prince's bay, in passing eastward, the trap cap is seen to descend across the bedding of the slates to the water's edge; and and at the point which forms the headland of the bay it appears clearly to cut the slates. Southward from the point the trap continues to cut the slates for two or three hundred yards, and then passes up over them and merges with the trap cap once more. The appearance is very much at one place as if there were a large dyke in direct continuity with the trap cap. At the same locality is another dyke distinctly cutting both slates and trap cap.

*Op. Cit. pp. 42, 46, 79, 80, 9J.
†Op. Cit. pp. 373, 374.

On the north side of Little Trout bay at a point about N. N. E. of McKellar's point, may be seen a very clear case of an intrusive sill. The sill is about four feet thick and is composed of a dark gray diabase. It has been injected along a structural plane in an older and thicker sheet of a pinkish weathering trap which presents a marked contrast to the sill. The latter has a dip of probably 10° to the southward. It is at the water's edge and presents a perfectly clean exposure. The upper and lower contacts of the sill with the enclosing rock are remarkably sharp and the details of this contact show the intrusive character of the sill. The petrographic variation within the sill itself establishes the same fact. It is a dense aphanitic rock at both upper and lower contacts, and in passing inward from the enclosing walls on either side towards the middle, the rock rapidly assumes a coarser texture and in the middle is a medium coarse grained rock.

On the south side of Little Trout bay, about its middle, the gray trap may be seen mounting up over the abrupt edges of the flat Animikie slates and then continuing along upon their upper surface as a cap. The relations are diagrammatically represented in the fig. 1. Practically the same relationship

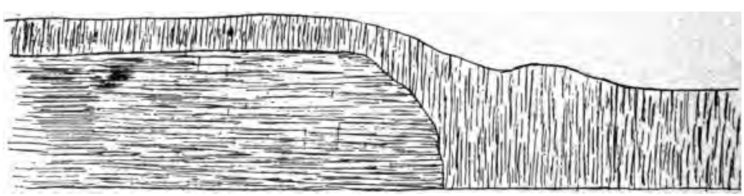


Fig. 1. Diagrammatic section showing the relation of the trap cap to the Animikie slates on the south side of Little Trout bay.

of trap and slate may be seen on the south side of the extremity of McKellar's point. Here again the trap mounts over the edge of the flat slates and then continues as a horizontal sheet resting upon them. There is here, however, one interesting point of difference from the conditions last referred to. The edges of the flat slates do not abut squarely upon the intersecting trap, but are sharply bent and broken at the contact, and in this appear to afford evidence of a fault strain or monocline flexure which preceded the rupture of the slates. (Fig. 2.) On the north side of Big Trout bay near the end of the bay, the great vertical cliffs show, besides the common thick cap of gray trap on the slates, two very well marked sills at lower levels and near the shore. These are nearly horizontal and lie

parallel with the bedding, the upper one being 10 or 12 feet thick and the lower one 4 or 5 feet. They are very distinctly columnar and very well defined basaltic columns of small dimensions may be easily removed from the edges of the sheets. Both of these sheets are fine grained aphanitic rocks at the top and bottom, and assume a coarser texture towards the middle. The details of the contact with the slates on both the upper and lower sides of sheets establish their intrusive character, there being small intersections of the bedding planes of the slates.

Near the extremity of the point which forms the south headland of Big Trout bay the trap is again seen to cut up through the flat slates and, after reaching a certain level, to be extended over them in the form of a horizontal sheet or cap.

On the south side of this same point, also near the extremity, the relations of trap and slate are revealed in a very clear and instructive cliff section. The trap here again mounts up over the abrupt clean edges of the slate and is, after reaching a certain level, extended horizontally upon them in the form of a cap. The upper surface of the slate formation is sharply step-like in places and uneven, and the contact of the trap and slate is therefore not a simple plane, but an irregular surface of fresh rupture along neighboring bedding planes with abrupt descents from one plane to another. Two-thirds of the way down the cliff is a second trap sheet, very much thinner and

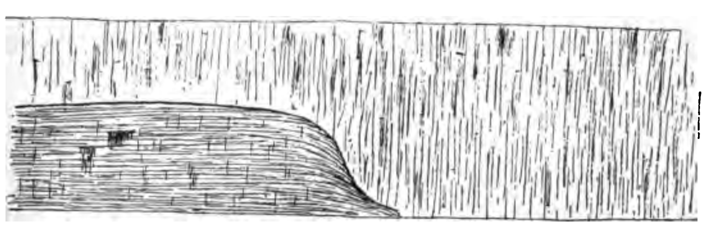


Fig. 2. Diagrammatic section on the south side of the extremity of McKellar's Point showing the relation of the trap cap to the Animikie strata.

intercalated with the slates. This is clearly an injected sill, for it may be seen in the cliff face to pass from one bedding plane, across the edge of the slates above and below, to another horizon about 10 feet higher. In the same section there is also a vertical dyke which seems to antedate the horizontal sill. The relations observed are represented diagrammatically in figure three. The relation of the small sill to the thicker mass of trap could not be clearly ascertained.

An interesting case of an intrusive sill is shown in the cliff section on the southeast side of Victoria island. Here a four-foot sill of gray diabase has been injected along the plane of contact between the Animikie slates and an earlier sheet

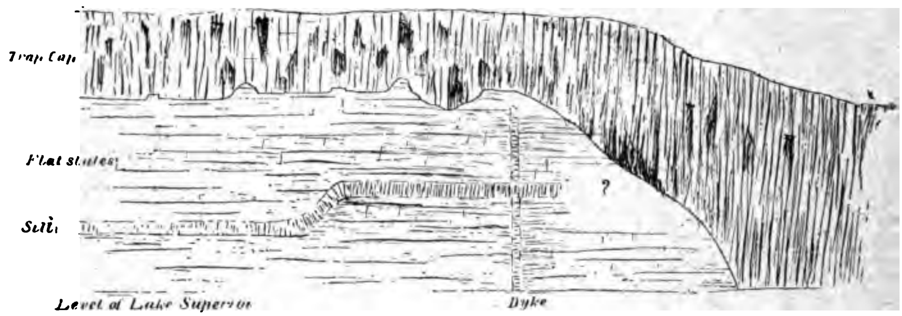


Fig. 3. Dirgrammatic section near the extremity of the point between Big Trout and Pigeon bays, showing the relation of the trap sills to the Animikie strata.

of red quartz-porphyry. The sill has a dip of 10° to 15°, and has the usual sharply-marked gradations in texture and structure in passing from the upper and lower surfaces towards the middle of the sheet. The difference in density of the rocks suggests that this has been the cause determining the contact plane of the quartz-porphyry as the plane of intrusion.* The local thickness of the sheet of quartz-porphyry is about forty or fifty feet.

Passage of sheets to the Horizon of the Keweenian—But not only are there numerous instances, such as those just cited, where the trap sheets cut across the bedding planes of the Animikie slates, but on following the coast eastward from Port Arthur it becomes apparent that the same sheets which cap the Animikie pass over to a higher geological horizon and cap the local stratigraphic column of the Keweenian (Nipigon), as was clearly recognized by Bell† many years ago.

In the vicinity of Black Sturgeon river, and on the shores and islands of Nipigon bay, there are abundant illustrations of great cliffs of Keweenian strata capped by thick sheets of trap, which are identical with those which cap the Animikie series at Thunder bay; and, although these sheets cannot be traced in absolute conformity in the interval, there are many outlying patches which fill the gap, and the writer agrees with Bell in the belief that there is no reasonable doubt as to the geological continuity of the trap sheets of Nipigon and Thunder bays, al-

*On this point cf. Gilbert. Geology of the Henry Mountains
†*Op. Cit.*

though he rejects Bell's view that they represent a volcanic overflow. These sheets, capping the Keweenian of Nipigon bay, are, of course, distinct from the true Keweenian lava beds and cannot be confounded with them. The relations of the trap sheets to the Keweenian strata are the same as those which they bear to the Animikie strata. Not only do the sheets rest as caps on the mesas and tilted orographic blocks of the Keweenian, but they also cut across the beds of the latter, precisely as they do in the Animikie. One of the best instances of the evident intrusion of these great trap sheets is near the mouth of Nipigon river, at the great red rock cliff which rises perpendicularly above the Canadian Paciffc railway track. Here a great mass of the diabase rises from the level of the lake, cuts across the horizontal bedding of the Keweenian for a vertical distance of 140 feet, and then spreads out over the surface in the form of a great sheet 125 feet thick. The Keweenian strata here, are very largely made up of bright vermilion red sandstones and purplish shales. These at the contact and for a hundred feet or so from it have been much disturbed, and have been bleached white. Two small dykes, apparently, though not demonstrably, apophyses from the greater mass of intrusive rock cut the sandstone and shales near this zone of alteration. The relations exhibited in the section are represented diagrammically in fiig. 4, the outlines of which are taken from a photograph.

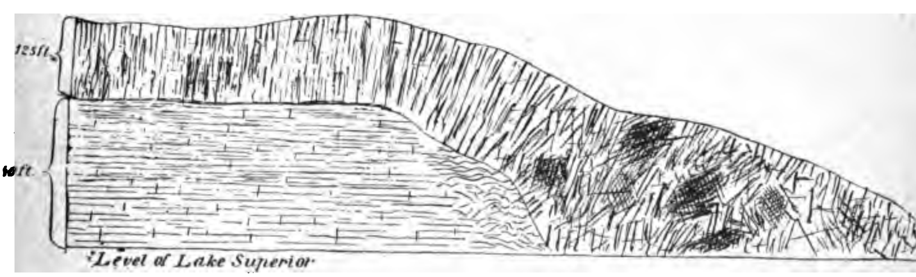


Fig. 4. Intersection of Keweenian strata by the trap sheet and the extention of the latter as a thick cap over the horizontal beds. Red-rock cliff at the mouth of Nipigon river.

In this region the Animikie is lacking and the higher Keweenian series rests directly on the Archæan. On both sides of Mazokamah bay, also, the trap sheets may be seen in the face of the the high bluffs to cut across the ruptured Keweenian strata.

At Rossport, at the extreme east end of Nipigon bay, the Animikie slates again appear between the old Archæan basement and the Keweenian strata, and here again the same trap may be observed as a single mass both to cut the Animikie slates vertically and to cap them horizontally.

THE LOWER CONTACT OF THE TRAP SHEETS.

A critical study of the details of the contacts of the trap sheets with the enclosing rocks yields sufficient evidence to demonstrate their intrusive character. Of course the fact that the great bulk of these sheets takes the form of mesa caps, from which the overlying slates have been removed almost entirely, renders it difficult to multiply observations on the upper contact. But even on the surface of some of the trap-caps there are sufficient remnants of the former volume of overlying strata, to afford precise and absolutely decisive evidence of their intrusive origin; and from the essential identity of the character of all the sheets, it would be a fair inference to conclude, that if one trap cap can be demonstrated to be intrusive, the others of the region of precisely the same physical features, and all lacking the character of volcanic flows, are also intrusive. But the thesis here laid down does not depend upon such an inference for its establishment. The lower contacts of the trap caps with the strata upon which they rest may be studied in practically an endless number of clean, bare, rock-walls; and the facts observed along the lower surface of the sheets is of high critical value—sufficient to demonstrate their intrusive character. On the supposition, which has been heretofore entertained, of the volcanic character of the trap sheets, there are two possible cases to be considered; (1) the flows might have been extravasated at the time of the deposition of the Animikie sediments which immediately underlie them. (2) They might have been extravasated after the induration and partial denudation of the underlying Animikie rocks.

In the first of these two suppositious cases, it is clear that a lava flowing over soft sediments of a clayey character, such as must have been the original condition of the slate commonly found beneath the trap caps, would give us a confused and very indefinite plane of contact; the sediments would be disturbed by the encroachment upon them of a great thick lava flow, and there would be more or less of a mixture of lava and sediments. All this is very far from being the condition which prevails at the contact of the trap sheets with the rocks upon which *they* repose. That contact can almost invariably be located

with knife edge precision, (see fig. 5). There is never any confusion of sedimentary rocks with the trap, and the sharply angular character of the broken edges of the slates, where they are imbedded in the trap, shows clearly that the slates were not in a soft condition at the time they were covered by the magma.

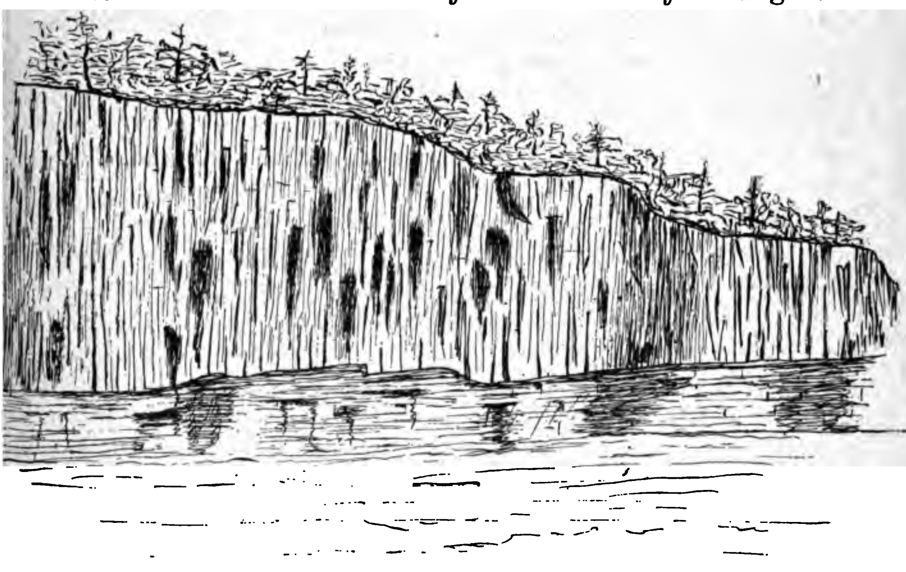


Fig. 5. Contact of the lower surface of the trap cap with underlying Animikie strata on the shore opposite Victoria Island.

The filling of minute fissures and cracks in the slate by apophyses from the trap sheet shows the same thing. The slates, then, were hard and brittle and had acquired their characteristic cleavage prior to the advent of the traps. The numerous cases of the trap sheets cutting across the bedding planes, as above recited, also shows the traps to be later than the induration of the slates and the development of the cleavage. It is clear, then, that even if the trap caps are volcanic flows, they are not contemporaneous with the deposition of the Animikie sediments. If then, they are volcanic flows at all they come under the second of the two possible suppositions. This implies that they were extravasated as flows on an eroded surface of the Animikie rocks. The study of the contact lends no countenance to this supposition. An eroded surface has two pronounced features which are absolutely lacking in the surface upon which the trap caps repose. These are (1) the common evidences of sub-aerial weathering and the sculpture of the surface, and (2) the accumulation of surface debris. The absence

of these features in any single section, or even in several localities, would not be conclusive; but when it is remembered that the nature of the exposures is such, that the unobscured contact may be critically examined along hundreds of miles of irregularly winding mesa scarps, the utter failure to find any evidence whatever of erosive action upon the surface covered by the trap caps, becomes full warrant for affirming that the surface has never been exposed to such agencies. The surface of the Animikie slates beneath the trap presents always the characters of a rock freshly ruptured and inveloped immediately in the trappean magma. Thus again the supposition that the sheets are surface flows has nothing to sustain it, and all the evidence directly supports the view that the sheets are intrusive.

THE UPPER CONTACT.

In most of the intercalated sheets the evidence of intrusion is so abundant that it is scarcely necessary to go into the details of their upper contact with the enclosing rock. It is sufficient to say that it presents no essential difference from the lower contact. The trap involves the sharp angular edges of the slate, where they have been ruptured by the disturbance; apophyses from the sheets extend (usually for not more than a few inches) into the cracks and fissures of the overlying slates; and angular fragments of the latter are quite frequently found imbedded in the trap. As has been stated, the opportunities of examining the upper contacts of the trap caps are few, owing to the general removal by erosion of the slates which once rested upon them. In the vicinity of Port Arthur, however, some remarkably fine sections may be very conveniently examined which show remnants of slates still reposing upon the trap caps; and such instances would be doubtless more frequently observed, were it not that the routes of travel only occasionally traverse the surface of the caps, and that the latter are very commonly covered with timber. The Port Arthur trap sheet is an extensive one, and not only underlies the town but extends inland for many square miles and skirts the shore of Thunder bay, being found on the points and islands. The average thickness is probably about 50 feet. On the surface of this sheet at several places may be seen patches of slate, adhering to it, and frequently sunk down into it. An excellent section is afforded in the railway cutting at the old Canadian Pacific railway station at Water street, Port Arthur. This section is shown in Plate VI. (frontispiece). The upper por-

tion of the trap sheet is very dense and compact, but it rapidly becomes coarser in descending through the thickness of the sheet. The plane of contact is on the whole, even, but is ragged or step like in detail, the steps being due to the fracturing of the slates by the invasion of the trap. *The slates are altered to the distance of over a foot above the trap.* In other sections the contact is still more step-like, and blocks of slate may be seen to be sunk down within the trap. The surface of the sheet, in places where it is perfectly evident that it has not been affected by erosion, is peculiarly domed with low flat un-

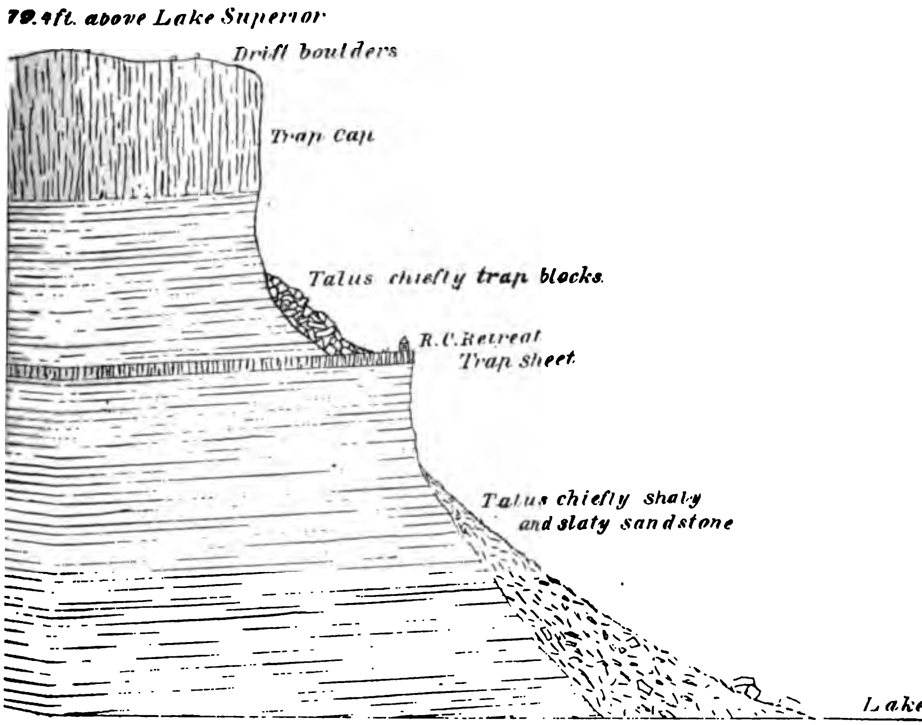


Fig 6. Diagrammatic section through McKay's Mountain, Fort William, showing the relation or Laccolitic Sills to the Animikie strata. Scale 1 inch, 280 feet.

dulations. The entire character of the upper surface of the Port Arthur sheet, which is one of the great caps of the region, although locally it descends to the level of the lake, is strictly analogous to that which may be observed on the projecting surface (a terrace of differential degradation) offered by the intecalated sheet at the Roman Catholic retreat on the face of McKay's mountain at Fort William. This sill is about 12 to 15 feet thick (see fig. 6) and has the same locally domed or undul-

atory surface with patches of the overlying slates sunk down into it and partially imbedded in it. This domed surface of the trap sheets has been also noted by Ingall* in other localities.

ALTERATION OF THE ENCLOSING ROCKS.

The alteration of the Animikie slates by intrusive masses of the same petrographical character and general dimensions, is very various in its extent. In some cases, as in the remarkable one at Pigeon point, described by Bayley, it amounts to a complete fusion of the invaded rocks and the mixture of such fused rock with the invading magma, giving rise to peculiar and exceedingly interesting petrographical types. In other cases the slates have only been altered to a hornfels to the extent of a few inches, or at most a few feet from the contact. Sometimes it requires a trained petrographical eye to detect that there has been any alteration whatever. The rocks immediately adjacent to the trap sheets, whether at their lower or their upper surface, are, however, always altered to the extent at least of making them recognizable as hornfels. They are hard and dense and frequently resemble somewhat the dense aphanitic facies of the trap at the contact, so that some geologists have confessed their inability to distinguish between them. This zone has not been subjected to systematic petrographical study, but in the few slides which the writer has examined, it is clear that the clastic structure of the rock has been more or less obscured by re-crystallization, and that the rock is characterized by the abundant development of minute pleochroic needles having parallel extinction, and resembling green hornblende but for the latter property. This alteration is sometimes associated with a bleaching of the rock; and in some cases there are suggestions of secondary glass having been formed. But it is not the intention of the writer to discuss the nature of the alteration. It is sufficient for his purpose to be able to state that there *is* a prevalent alteration of the Animikie slates, both above and below the trap sheets, which is clearly ascribable to their invasion within the slates as ingneous masses.

SUMMARY.

The argument may be summarized briefly:

I—The trap sheets associated with the Animikie strata are not volcanic flows, because of the combination of the following facts:

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* *Op. cit.*

1. They are simple geological units, not a series of overlapping sheets.
2. They are flat with uniform thickness over areas more than one hundred square miles in extent, and where inclined, the dip is due essentially to faulting and tilting.
3. There are no pyroclastic rocks associated with them.
4. They are never glassy.
5. They are never amygdaloidal.
6. They exhibit no flow structure.
7. They have no ropy or wrinkled surface.
8. They have no lava-breccia associated with them.
9. They came in contact with the slates after the latter were hard and brittle and had acquired their cleavage; yet they never repose upon a surface which has been exposed to sub-aerial weathering.

II.—They are intrusive sills because of the combination of the following facts:

1. They are strictly analogous to the great dykes of the region. (*a*) In their general relations to the adjacent rocks, and in their field aspect. (*b*) In that both the upper and lower sides of the sheets have the facies of a dense aphanitic rock, which grades towards the middle into a coarsely crystalline rock.
2. They have a practically uniform thickness over large areas.
3. The columnar structure extends from lower surface to upper surface, as it does from wall to wall in the dykes.
4. They intersected the strata above and below them after the latter had been hard and brittle.
5. They may be observed in direct continuity with dykes.
6. They pass from one horizon to another.
8. The bottom of the sedimentary strata above them, whereever it is observable, is a freshly ruptured surface.
9. Apophyses of the trap pass from the main sheet into the cracks of the slate above and below.
10. The trap sheets, particularly at the upper contact, hold included fragments of the overlying slates.
11. They locally alter the slates above and below them.

GEOLOGICAL CONSEQUENCES.

In the lake Superior region the lowest great division of the Palæozoic is known to the Minnesota survey as the Taconic system. This system embraces two groups, viz: The Animikie and the Keweenian (Keweenawan). Between the Animikie and the Keweenian there is an interval of erosion and a consequent